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Advanced Food Technology Workshop Report – Volume II

Space and Life Sciences Directorate
Habitability and Environmental Factors Division

March 10, 2003

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

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HABITABILITY AND ENVIRONMENTAL FACTORS DIVISION

NASA–LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS

Advanced Food Technology Workshop Report

Volume II

Date March 10, 2003

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REVISIONS

DATE	AUTHOR	APPROVALS: SECTION	APPROVALS: BRANCH	APPROVALS: DIVISION	APPROVALS	REV. LETTER

Table of Contents

Advanced Food Technology Workshop Agenda
NASA Johnson Space Center

April 3, 2002:

Time	Topic	Speaker
7:45 – 8:00	Continental Breakfast	
8:00 – 8:10	Welcome and Introductions	Jitendra Joshi
8:10 – 8:15	Logistics	Melvin Moses
8:15 – 9:00	Purpose of Workshop and Background Information	Michele Perchonok
9:00 – 9:30	Overview of ALS Program	Don Henninger
9:30 – 10:00	Shuttle and ISS Food Systems	Vickie Kloeris
10:00 – 10:15	Break	
10:15 – 10:45	Systems Analysis	Mike Ewert
10:45 – 12:00	Working Groups	
12:00 – 1:30	Lunch with speakers (30 minute lunch then move into auditorium for speakers)	Dave Wolf (tentative) Al Holland - Psychological Issues)
1:30 – 3:30	Working Groups	
3:30 – 4:00	10 minute working group summary	Working Group Leads
4:00 – 5:30	Tours of Food Lab and FPS DF	(Pending badge approval)

April 4, 2002:

Time	Topic	
7:45 – 8:15	Meeting with Leads	
8:00 – 8:15	Continental Breakfast	
8:15 – 10:00	Working Groups	
9:30 – 9:50	Break	
9:50 – 11:45	Working Groups	
11:45 – 1:15	Lunch with speakers (30 minute lunch then move into auditorium for speakers)	Dr. Scott Smith - Nutritional Requirements Dr. Helen Lane – Critical Path Review
1:15 – 4:15	Working Groups	

4:15 – 5:00	15 minute working group summary	Working Group Leads
5:00 – 5:30	Meeting with leads	
5:00 – 7:00	Reception at CASS	

April 5, 2002:

Time	**Topic**
7:45 – 8:15	Meeting with Leads
8:00 – 8:15	Continental Breakfast
8:15 – 9:30	Working Groups
9:30 – 10:00	Break
10:00 – 12:00	Presentations from three working groups
12:00	Dismissal of Groups
12:00 – 1:00	Lunch with Leads (at a restaurant – not at CASS)
1:00 – 3:00	Leads meet with NASA coordinators

Advanced Food Technology Attendees; April 3 – 5, 2002

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Technology Readiness Levels

TECHNOLOGY READINESS LEVELS *

BASIC RESEARCH

RESEARCH TO PROVE FEASIBILITY

TECHNOLOGY DEVELOPMENT

TECHNOLOGY DEMONSTRATION

SYSTEM DEVELOPMENT

SYSTEM TEST/ OPERATIONS

1. BASIC PRINCIPLES OBSERVED AND REPORTED
2. TECHNOLOGY CONCEPT AND/OR APPLICATION FORMULATED
3. ANALYTICAL AND EXPERIMENTAL CRITICAL FUNCTION AND/OR CHARACTERISTIC PROOF-OF-CONCEPT
4. COMPONENT AND/OR BREADBOARD VALIDATION IN LABORATORY ENVIRONMENT
5. COMPONENT AND/OR BREADBOARD VALIDATION IN RELEVANT ENVIRONMENT
6. SYSTEM/SUBSYSTEM MODEL OR PROTOTYPE DEMONSTRATION IN A RELEVANT ENVIRONMENT (GROUND OR SPACE)
7. SYSTEM PROTOTYPE DEMONSTRATION IN A SPACE ENVIRONMENT
8. ACTUAL SYSTEM COMPLETED AND “FLIGHT QUALIFIED” THROUGH TEST AND DEMONSTRATION
9. ACTUAL SYSTEM “FLIGHT PROVEN” THROUGH SUCCESSFUL MISSION OPERATIONS

* From SSP 50198 (11/22/95)

Technology Assessment Forms

Food Packaging Research and Technology Development Evaluation Criteria for Advanced Food Technologies (AFT)

1 INTRODUCTION

The goal of this AFT workshop is to provide input to NASA to develop a research and technology development strategy for AFT. Candidate food processing, food preservation, and food packaging technologies for possible use in future space-based human life support systems are to be assessed at this workshop. Each candidate technology is to be independently assessed in terms of established criteria including mass, power, volume, reliability, use of expendables, technology readiness level, and operational scenarios (e.g. microgravity vs. hypogravity; vehicle vs. planetary surface applications). Each candidate technology will also be independently assessed for final product acceptability, shelf life, safety, and nutritional content.

This document specifically addresses the technologies used for food packaging. The primary objective of the Food Packaging portion of the Advanced Food System is to protect the preserved or stored food. Emphasis should be on the packaging needed for the prepackaged food system. However, packaging may be used protect the ingredients made from the processed crops and hence should also be considered. These technologies include the actual packaging materials and the equipment used to produce and if applicable form the packaging material. The intent is to consider the technologies that can be used to provide the Advanced Food System with packaged food that has a shelf life of 3 – 5 years. The food must also be safe, acceptable, and nutritious. The packaging material and equipment may also be used to package food ingredients processed on the planetary surface. The information derived from this document will be used to provide managers and systems analysts with needed information on what technologies are available and what their performance, safety and cost characteristics are. Managers and systems analysts will then use this information to match mission requirements with technologies that can meet those requirements. In this sense, this form aids in guiding decision-making for research and technology development (R&TD) funding.

Section 2 provides the list of possible missions and the top-level AFT requirements for those missions. Prior to completing Section 3, Section 2 should be understood. Section 3 is to be completed with one of the listed missions and food technologies and requirements in mind.

Within Section 3, Sections 3.1 through 3.4 request background information on the technology. Sections 3.5 through 3.16 request information (criteria) that will be used by management and systems analysts to evaluate the effectiveness of the technology for a particular mission. The "TRL for Mandatory Reporting" indicates the Test Readiness Level (TRL) at which it is mandatory that information on each criterion be reported on this form. Refer to Appendix A for a brief description of the TRL scale. **Thus, the researcher/technology developer should fill out Section 3 for all criteria that have a TRL for Mandatory Reporting that is equal to or less than the current TRL of the technology.** Reporting is *encouraged* for criteria with TRLs for Mandatory Reporting greater than the TRL of the technology. It is understood that estimates may be used in the filling out of these forms. These forms are to provide the Systems Integration, Modeling and Analysis group with a starting point for their analysis. An effort has been made to organize criteria in this document by ascending TRL for Mandatory Reporting.

Refer to Appendix B for acronyms. If you have any questions, please contact Michele Perchonok at mperchon@ems.jsc.nasa.gov (281) 483-7632.

2 APPLICABLE MISSION/MISSION LEG AND ASSOCIATED REQUIREMENTS FOR AFT

When completing this document, the AFT requirements for each possible mission must be considered. The possible missions are selected from the ALS Reference Missions Document (RMD) (JSC-39502). **It only makes sense to complete this form for a particular technology, in reference to a particular mission, if that technology meets one or more of the AFT requirements (listed below) in that mission.**

For the following scenarios, the assumption that no useable natural resources are available shall be made. While there will probably be a minimal amount of certain natural resources, do not consider there to be any when assessing the technologies. However, do not rule out technologies because they have a low return in some resource areas.

AFT Requirements for Each Mission/Mission Leg (key words are underlined):

- Mars Transit Vehicle: Approximately 180 day transit from Earth to Mars each way. The primary food system will be prepackaged food. Minimally processed foods such as salad crops may be grown in a growth chamber. Water is probably the only resource that might be desired. Top-Level AFT Requirements: <u>Prepackaged food Items with a shelf life of 3 – 5 years that are safe, acceptable and provide the correct nutrition. Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops</u>.
- Mars Surface Habitat Lander: Approximately 600 day stay on Mars per mission. A plant chamber would be available and would be responsible for growing more than just garden crops, and grown food would be the primary diet. Top-Level AFT Requirements: <u>Prepackaged food Items with a shelf life of 3 – 5 years that are safe, acceptable and provide the correct nutrition. Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops</u>.
- Evolved Mars Base: Approximately 600 day stay on Mars per mission. However, the base may be fully functional for more than 10 years. This mission relies on plants for nearly all of the diet (approximately 90%). Top-Level AFT Requirements: <u>Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops. Some food preservation technologies may be used to preserve the processed ingredients.</u>

3 INFORMATION TO BE COMPLETED BY RESEARCHER/TECHNOLOGY DEVELOPER

3.1 Name of Technology:

3.2 If commercial, state manufacturer and specification or reference number:

3.3 Current TRL (Refer to Appendix A):

3.4 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

3.5 Functions

TRL for Mandatory Reporting: 1

What are the objectives in implementing the technology in accordance with the mission requirements for AFT? Please use the same wording as given in the mission requirements section (Section 2). The technology may satisfy more than one of the requirements for a particular mission in Section 2, in which case the researcher/technology developer should enumerate the satisfied requirements.

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

3.6 Hazard Identification

TRL for Mandatory Reporting: 1

It is expected that these technologies will be used on Earth. However, in case the crops or food ingredients produced from the crops are further packaged, it is necessary to identify the hazards. Hazards should be identified related to the equipment used to produce the packaging material, the packaging material itself, or the package configuration. Examples of hazards include but are not restricted to microbial issues, hazardous chemical use, high temperature, high pressure, equipment mechanical hazards, and generation of unsafe gas emissions.

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

3.7 Material Physical Factors

TRL for Mandatory Reporting: 2

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food

Material Chemical Composition

Material/ Technology	Chemical composition	Describe any offgassing concerns

Evaluate the Temperature limitations of the packaging material:

Material/ Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^{o}C)	Effect of temperature on packaging and food interaction

3.8 Packaging Design

TRL for Mandatory Reporting: 2

Technology	How does package design enhance food quality?	How has convenience affected the package design?

3.9 Packaging Material Stability

TRL for Mandatory Reporting: 2

Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for*

* dehydrated, thermostabilized, frozen, etc.

3.10 Food Packaging Equipment, Packaging Material Information

TRL for Mandatory Reporting: 2

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness?

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material

What would prevent the current packaging equipment from being operated upside down in a terrestrial environment?

Packaging Equipment:

Equipment Technology	Suitable for ground operations?	Suitable for planetary surface	Unique to one packaging technology? If not, list other technologies with same traits

3.11 Packaging Equipment Specification

For each food packaging technology, estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

(CM-h = crewmember-hour)

	Does equipment have vacuum or gas flush capability?	Equipment Mass (kg)	Equipment Volume (m^3)	Power per use (kW)	Water Usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)						
Ground-based (TRL 4)						

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Material/Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

3.12 Equipment Clean-up

TRL for Mandatory Reporting: 3

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Material/ Technology	Describe Equipment Clean-up	Water usage (liters per cleaning)	Chemical usage	CM-h per clean-up

3.13 Equipment Lifetime

TRL for Mandatory Reporting: 4

Describe the expected lifetime of the food packaging equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/ Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule

What relevant compounds and circumstances will degrade the performance of or damage the technology?

3.14 System Integration

TRL for Mandatory Reporting: 4

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system

3.15 Reliability, Monitoring and Control

TRL for Mandatory Reporting: 4

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe packaging reliability	Evaluate packaging risk

What sensor data and controls are necessary to insure the packaging equipment is functioning properly? What long term measurements are necessary to insure the functionality of the packaging material? What data processing is needed to relate the sensor data to the control data?

Technology	Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs	Test available to measure quality of packaging material?

3.16 Technology Advances

TRL for Mandatory Reporting: 4

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?

Food Preservation Research and Technology Development Evaluation Criteria for Advanced Food Technologies (AFT)

1 INTRODUCTION

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This document specifically addresses the technologies used for food preservation. The primary objective of the Food Preservation portion of the Advanced Food System is to extend the shelf life of the food. Emphasis should be on the preservation methods used on Earth to provide the prepackaged food system. However, preservation technologies may be used to extend the shelf life of the ingredients made from the processed crops and hence should also be considered. The intent is to consider the technologies that can be used to provide the Advanced Food System with packaged food that has a shelf life of 3 – 5 years. The food must also be safe, acceptable, and nutritious. The information derived from this document will be used to provide managers and systems analysts with needed information on what technologies are available and what their performance, safety and cost characteristics are. Managers and systems analysts will then use this information to match mission requirements with technologies that can meet those requirements. In this sense, this form aids in guiding decision-making for research and technology development (R&TD) funding.

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Refer to Appendix B for acronyms. If you have any questions, please contact Michele Perchonok at mperchon@ems.jsc.nasa.gov (281) 483-7632.

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3.2 If commercial, state manufacturer and specification or reference number:

3.3 Current TRL (Refer to Appendix A):

3.4 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

3.5 Functions

TRL for Mandatory Reporting: 1

What are the objectives in implementing the technology in accordance with the mission requirements for AFT? Please use the same wording as given in the mission requirements section (Section 2). The technology may satisfy more than one of the requirements for a particular mission in Section 2, in which case the researcher/technology developer should enumerate the satisfied requirements.

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

3.6 Hazard Identification

TRL for Mandatory Reporting: 1

It is expected that these technologies will be used on Earth. However, in case the crops or food ingredients produced from the crops are further preserved, it is necessary to identify the hazards. Examples of hazards include but are not restricted to microbial issues, hazardous chemical use, high temperature, high pressure, and generation of unsafe gas emissions.

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

3.7 Food Shelf Life

TRL for Mandatory Reporting: 2

Shelf life can be defined when the safety, nutrition, and/or acceptability do not meet the product's or food items specifications.

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

3.8 Product Attributes

TRL for Mandatory Reporting: 2

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food					
Processed Food					

3.9 Gravity Dependence

TRL for Mandatory Reporting: 2

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life

3.10 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

(**CM-h = crewmember-hour**)

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)					
Ground-based (TRL 4)					

Can the equipment be automated? To what degree?

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

3.11 Equipment Clean-up

TRL for Mandatory Reporting: 3

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Material/ Technology	Describe equipment clean-up	Water usage (liters per cleaning)	Chemicals used for processing	CM-h per clean-up

3.12 Equipment Lifetime

TRL for Mandatory Reporting: 4

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/ Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule

What relevant compounds and circumstances will degrade the performance of or damage the technology?

3.13 System Integration

TRL for Mandatory Reporting: 4

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system

3.14 Reliability, Monitoring and Control

TRL for Mandatory Reporting: 4

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs

3.15 Technology Advances

TRL for Mandatory Reporting: 4

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?

Data Sources

TRL for Mandatory Reporting: 0

What references and data sources were used in completing this form?

Post-harvest Processing Research and Technology Development Evaluation Criteria for Advanced Food Technologies (AFT)

1 INTRODUCTION

The goal of this AFT workshop is to provide input to NASA to develop a research and technology development strategy for AFT. Candidate post-harvest processing, food preservation, and food packaging technologies for possible use in future space-based human life support systems are to be assessed at this workshop. Each candidate technology is to be independently assessed in terms of established criteria including mass, power, volume, reliability, use of expendables, technology readiness level, and operational scenarios (e.g. microgravity vs. hypogravity; vehicle vs. planetary surface applications). Each candidate technology will also be independently assessed for final product acceptability, shelf life, safety, and nutritional content.

This document specifically addresses the technologies used for post-harvest processing. The primary objective of the Post-harvest Processing portion of the Advanced Food System is to make edible ingredients form the harvested crops. These ingredients, when used in the menu, must be safe, nutritious, and acceptable. The intent is to consider the technologies that can be used to provide the Advanced Food System with food ingredients processed from the crops grown on the planetary surface. The processed food must be safe, acceptable, and nutritious. The information derived from this document will be used to provide managers and systems analysts with needed information on what technologies are available and what their performance, safety and cost characteristics are. Managers and systems analysts will then use this information to match mission requirements with technologies that can meet those requirements. In this sense, this form aids in guiding decision-making for research and technology development (R&TD) funding.

Section 2 provides the list of possible missions and the top-level AFT requirements for those missions. Prior to completing Section 3, Section 2 should be understood. Section 3 is to be completed with one of the listed missions and food technologies and requirements in mind.

Within Section 3, Sections 3.1 through 3.4 request background information on the technology. Sections 3.5 through 3.15 request information (criteria) that will be used by management and systems analysts to evaluate the effectiveness of the technology for a particular mission. The "TRL for Mandatory Reporting" indicates the Test Readiness Level (TRL) at which it is mandatory that information on each criterion be filled in on this form. Refer to Appendix A for a brief description of the TRL scale. **Thus, the researcher/technology developer should fill out Section 3 for all criteria that have a TRL for Mandatory Reporting that is equal to or less than the current TRL of the technology.** Reporting is *encouraged* for criteria with TRLs for Mandatory Reporting greater than the TRL of the technology. It is understood that estimates may be used in the filling out of these forms. These forms are to provide the Systems Integration, Modeling and Analysis group with a starting point for their analysis. An effort has been made to organize criteria in this document by ascending TRL for Mandatory Reporting.

Refer to Appendix B for acronyms. If you have any questions, please contact Michele Perchonok at mperchon@ems.jsc.nasa.gov (281) 483-7632.

2 APPLICABLE MISSION/MISSION LEG AND ASSOCIATED REQUIREMENTS FOR AFT

When completing this document, the AFT requirements for each possible mission must be considered. The possible missions are selected from the ALS Reference Missions Document (RMD) (JSC-39502). **It only makes sense to complete this form for a particular technology, in reference to a particular mission, if that technology meets one or more of the AFT requirements (listed below) in that mission.**

For the following scenarios, the assumption that no useable natural resources are available shall be made. While there will probably be a minimal amount of certain natural resources, do not consider there to be any when assessing the technologies. However, do not rule out technologies because they have a low return in some resource areas.

AFT Requirements for Each Mission/Mission Leg (key words are underlined):

- Mars Transit Vehicle: Approximately 180 day transit from Earth to Mars each way. The primary food system will be prepackaged food. Minimally processed foods such as salad crops may be grown in a growth chamber. Water is probably the only resource that might be desired. Top-Level AFT Requirements: Prepackaged food Items with a shelf life of 3 – 5 years that are safe, acceptable and provide the correct nutrition. Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops.
- Mars Surface Habitat Lander: Approximately 600 day stay on Mars per mission. A plant chamber would be available and would be responsible for growing more than just garden crops, and grown food would be the primary diet. Top-Level AFT Requirements: Prepackaged food Items with a shelf life of 3 – 5 years that are safe, acceptable and provide the correct nutrition. Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops.
- Evolved Mars Base: Approximately 600 day stay on Mars per mission. However, the base may be fully functional for more than 10 years. This mission relies on plants for nearly all of the diet (approximately 90%). Top-Level AFT Requirements: Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops. Some food preservation technologies may be used to preserve the processed ingredients.

3 INFORMATION TO BE COMPLETED BY RESEARCHER/TECHNOLOGY DEVELOPER

3.1 Name of Technology:

3.2 If commercial, state manufacturer and specification or reference number:

3.3 Current TRL (Refer to Appendix A):

3.4 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

3.5 Functions

TRL for Mandatory Reporting: 1
What are the objectives in implementing the technology in accordance with the mission requirements for AFT? Please use the same wording as given in the mission requirements section (Section 2). The technology may satisfy more than one of the requirements for a particular mission in Section 2, in which case the researcher/technology developer should enumerate the satisfied requirements.

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

3.6 Hazard Identification

TRL for Mandatory Reporting: 1

Hazards should be identified related to the equipment used to process the crops. Examples of hazards include but are not restricted to microbial issues, hazardous chemical use, high temperature, high pressure, equipment mechanical hazards, and generation of unsafe gas emissions.

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

3.7 Shelf Life

TRL for Mandatory Reporting: 2

Based on the technology, evaluate or describe the stability of the processed crop. Please state the stability of the harvested crops when stored under optimum conditions. Those conditions should be stated in the table (4^{th} column).

Technology	Harvested crop shelf life (years)	Describe steps taken to ensure no loss in crop functionality (temperature, relative humidity, etc.)	Describe steps taken to ensure that ingredients remain stable after post-harvest processing.	Nutritional content of processed crop vs. original food state	Type of packaging needed to provide highest degree of food acceptability

3.8 Gravity Dependence

TRL for Mandatory Reporting: 2

Does the processing technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? In other words, what would prevent the current processing equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity will affect crop functionality or shelf life

3.9 Processing Equipment Specifications

For each component in the post-harvest processing technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

(**CM-h = crewmember-hour**)

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Emissions generated during processing	Crewtime (CM-h per use)
Technology: Theoretical (TRL 2)						
Ground-based (TRL 4)						

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Can the equipment be automated? To what degree?

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to reach TRL=5	Labor costs to bring technology to TRL=5

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

3.10 Equipment Clean-up

TRL for Mandatory Reporting: 3

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Technology	Describe equipment clean-up	CM-h per clean-up	Water usage (liters per cleaning)	Chemicals used for processing

3.11 Equipment Lifetime

TRL for Mandatory Reporting: 4

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule

What relevant compounds and circumstances will degrade the performance of or damage the technology?

3.12 System Integration

TRL for Mandatory Reporting: 4

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this processing technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system

3.13 Post-harvest Processing Operations

Technology	Suitable for ground operations?	Suitable for planetary surface (partial gravity)	Unique to one processing technology? If not, list other technologies with same traits

3.14 Reliability, Monitoring and Control

TRL for Mandatory Reporting: 4

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs

3.15 Technology Advances

TRL for Mandatory Reporting: 4

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?

Data Sources

TRL for Mandatory Reporting: 0

What references and data sources were used in completing this form?

Technology Assessments: Food Packaging

1.0 Food Packaging: General packaging information

1.1 If commercial, state manufacturer and specification or reference number:

1.2 Current TRL (Refer to Appendix A):

1.3 Mission(s) for which this form is being completed (check one or more of the following options):

- ☐ Mars Dual Lander Transit Vehicle
- ☐ Mars Dual Lander Surface Habitat
- ☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

1.4 Function: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

The need for a 3-5 year shelf life to satisfy mission constraints limits the packaging material options. Barriers are needed to gas (oxygen, water vapor, volatile flavors and aromas, etc.), water, and light to preserve the quality of the foods. The packages must also withstand the necessary heating for producing thermostabilized foods. High heat treatments on packaged foods will all but eliminate microbiological concerns in the thermostabilized food supply; however, quality degradation due to possible enzyme activity must be evaluated. Although dehydrated, freeze-dried, and intermediate moisture foods may be acceptable for the first months of the mission, the quality concerns associated with these products over the extended 3-5 year time frame limit their use for the latter parts of the mission. In the trade-off between quality and weight/volume concerns, quality (and variety) must take precedence to maximize the likelihood that the astronauts will maintain an appropriate level of food intake.

The areas of edible and biodegradable packaging do not currently meet the mission constraints. Most laminate polymer structures without a foil/metallized layer also do not meet the mission requirements; however, the increasing variety of high-barrier polymers, thin glass-like coatings, and/or adding an oxygen scavenger to the laminate structures could improve their functionality. Storing the foods in a dark, temperature- reduced (<70F) environment also could extend the shelf-life of these products. Metal cans and tubes can provide the needed shelf-life; however, weight and space restrictions, and possibly quality of the products in a tube, limit their use. A reusable metal canning jar (screw cap lid with compound to ensure a hermetic seal) could decrease the overall weight of packaging by allowing multiple uses of the same package/can on the planetary surface, if appropriate processes are designed to incorporate use of these cans. Current packaging used for MREs is a viable option with a high TRL for use during a 3-5 year mission.

1.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development?

Producing plastic polymer films on a planetary surface is not a viable option because of concerns with generating unsafe gasses, weight/volume of the equipment and polymer supplies, and limited recyclability or reuse of laminate structures. Producing edible films on a planetary surface would likely tie up resources needed elsewhere, and functionality of edible films produced on a planetary surface will not meet mission constraints. Producing packaging materials from a waste stream would possibly require less ESM. One option would be to produce packaging materials from lignin; however, there might be too many hazards associated with producing lignin packages, and the functionality of this product may not meet mission requirements. A more viable option seems to be sending up pre-formed pouches that only require filling, sealing, and thermal processing.

1.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Oxygen permeability cm^3 mil/ $100in^2$ day atm	Light Transmissivity	Water vapor permeability cm^3 mil/ $100in^2$ day atm	Material mass per area Yield of .001 in thick plastic film = m^2/kg	Packaging Type (flexible, semi-rigid, rigid)
Saran (PVDC)	0.1 - 1	Good	0.09 – 0.2	24	Flexible
PET	4.8			29	Flexible
Aluminum metallized film/ foil					Flexible
Metal can					Rigid
Saran HB	0.08	Good	0.05		Flexible
Nylon 6	2.6	Poor	10		Semi
Polypropylene	150	Good	0.5		Semi
CPET	5	Good	2-3		Semi
coPET	10	Good	?		Flexible
Metallized PET	0.08	None	0.05		Flexible - Semi
HDPE	150	Poor	0.3		Semi
MDPE	250	Poor	0.7		Semi
LDPE	420	Good	1-1.5		Flexible
Polystyrene	350	Good	7-11		Rigid
EVOH F	0.01(0%RH) 1.22 (100%RH)	Good Good	3.8		Flexible
EVOH E	0.31(0%RH) 0.65 (100%RH)	Good Good	1.4		Flexible

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
Metal can		>5	Yes	Possible	
Metal canning jar	Reusable	>5	Yes	Yes	
MRE or metallized pouch		>5	No	No	
Polymer laminate pouch		>5	No/maybe	No	
PVDC		None	1	1	
Nylon		None	4	9	
Polyolefins		None	9	9	
Polyesters		None	9	9	
EVOH (in multilayer)		None	4 (recyclable, but is mixture of multilayer)	9	

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
Most plastic polymers	Varied	Yes if forming pouches in an enclosed environment, not necessarily if only sealing pouches
Metal cans	Steel, aluminum	None

Evaluate the Temperature limitations of the packaging material

Material/ Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (°C)	Effect of temperature on packaging and food interaction *(generalize – higher temp. more interactions likely)*
PET	Y	Y	Frozen to 204	
PVDC	Y	Y	? to 100	Low barrier properties at high temp.
Metal can	N	Y	Wide	
MRE pouch	N	Y	Wide	
Saran HB	Y	Y	? to 100	
Nylon 6	Y	Y	? to 55-80	
Polypropylene	Y	Y	? to 77-121	
CPET	Y	Y	? to 63-100	
coPET	Y	Y	? to 70-100	
Metallized PET	N	Y	? to 63-100	
HDPE	Y	Y	-59 to 42-84	
MDPE	Y	Y	-70 to 40-75	
LDPE	Y	Y	-70 to 41-45	
Polystyrene	Y	Y	? to 69-91	
EVOH	Y	Y	? to 80-100	

1.7 Packaging Design

Technology	How does package design enhance food quality?	How has convenience affected the package design?
Metal can	High barrier – long shelf life possible	
MRE pouch	Thinner profile than can allows for more rapid heating/cooling	
Laminate polymer pouch	Vacuum sealable, can see product	

1.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for
Metal can				Limited	Thermostabilized
MRE pouch				Somewhat limited	Thermostabilized
Polymer laminates	Depends on polymer		Somewhat limited	Slightly limited	Some thermostabilized, dehydrated, frozen
Oxygen scavenger in polymer					
Saran (PVDC)	Unknown	Unknown	3	3	
Saran HB			?	?	
Nylon 6			9	9	
Polypropylene			7	9	
CPET			6	7	
coPET			6	9	
Metallized PET			5	4	
HDPE			8	9	
MDPE			7	9	
LDPE			5	9	
Polystyrene			3	9	
EVOH			5	9	

1.9 Food Packaging Equipment, Packaging Material Information – no information provided

What would prevent the current packaging equipment from being operated upside down in a terrestrial environment?

Equipment technology	Suitable for ground operations?	Suitable for planetary surface	Unique to one packaging technology? If not, list other technologies with same traits
Vacuum sealer	Y	Y	
Heat sealer	Y	Y	
Co-extrusion slot orifice cast film	Y	N	
Co-extrusion multichannel die for blown film extrusion	Y	N	

1.10 Packaging Equipment Specification – no information provided

1.11 Equipment Clean-up – no information provided

1.12 Equipment Lifetime – no information provided

1.13 System Integration – no information provided

1.14 Reliability, Monitoring and Control – no information provided

1.15 Technology Advances – no information provided

1.16 Data Sources - no information provided

2.0 Food Packaging: High barrier packaging materials for intermediate shelf life (12 – 15 months)

2.1 If commercial, state manufacturer and specification or reference number: Cryovac, Curwood, Pechiney,

2.2 Current TRL (Refer to Appendix A): 6

2.3 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

2.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops. Some food preservation technologies may be used to preserve the processed ingredients.

These are packaging materials with an oxygen barrier system for holding oxygen sensitive foods for 12 to 15 months at 20 C, 1 atm pressure, and 75% RH. Shelf life can be extended by reducing storage temperature, RH, and/or oxygen partial pressure. Vacuum packaging is necessary. For liquid products, the package is hot filled at 185 to 195 F to kill any spoilage and vegetative pathogenic bacteria. The limitation of this application is the heat treatment required for filling and the need for refrigeration. The material can also be used for s. Can complement refrigerated, low acid, hot fill, high acid shelf stable, reduced water activity, and dehydrated products. For the shelf stable reduced water activity products, the package may be purged with nitrogen prior to sealing. An oxygen scavenging system may also be used to scavenge residual oxygen in the package headspace.

Shelf life can be reduced with elevated temperature and increased oxygen and possibly energy input of low dose radiation (technology gap)

2.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Post production microbial contamination of the packaging material. This can be controlled with GMP's, HACCP, irradiation, and sanitizers.

2.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging/Type (flexible, semi-rigid, rigid)
High barrier packaging materials for intermediate shelf life	10-cc/m^2/24 hrs. @ 21 C	Clear or opaque	0.2 to 0.5 gm/100 in^2/24 hr @ 38 C, 100% RH	At 3.5 to 7.0 mils, about 8o to 161 gm/m^2	Flexible

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?	Effect of physical properties upon acceptability of food
High barrier packaging materials for intermediate shelf life	High barrier flexible plastic film for packaging applications that utilize vertical form fill and seal equipment or pre-made pouches	Not degradable by microorganisms	1	N	Protects the product from oxidation. It is not an absolute barrier, but sufficient for 12 to 15 month shelf life.

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
High barrier packaging materials for intermediate shelf life	Multilayer, multi-constituent thermoplastic films	None

Evaluate the Temperature limitations of the packaging material:

Material/Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^oC)	Effect of temperature on packaging and food interaction
High barrier packaging materials for intermediate shelf life	Y	Y	The materials can be used for holding during cooking or for re-heating.	No interaction expected

2.7 Packaging Design

Technology	How does package design enhance food quality?	How has convenience affected the package design?
High barrier packaging materials for intermediate shelf life	Prevention of product oxidation	Easy open or dispensing features are typically attached to these packages.

2.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for
High barrier packaging materials for intermediate shelf life	Maximum is unknown	9	8	Not designed for thermoforming applications	Thermally treated and refrigerated, reduced water activity, dehydrated, and frozen products.

2.9 Food Packaging Equipment, Packaging Material Information

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? – Unknown

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
High barrier packaging materials for intermediate shelf life	No dependence known	No known effect

What would prevent the current packaging equipment from being operated upside down in a terrestrial environment?

It depends on the complexity of the equipment. For this application, A small sealer or vacuum packaging unit would be used with pre-made bags. This equipment should operate upside down.

Equipment Technology	Suitable For Ground Operations?	Suitable For Planetary Surface	Unique To One Packaging Technology?
Small vacuum packaging systems for pre-made bags or vertical form fill and seal (VFFS) equipment for rollstock film. VFFS system would most likely not be applicable for planetary operation because of its size and complexity.	Yes - small vacuum packaging unit	High probability	A small vacuum/gas flush equipment could be used for a variety of products that would benefit from a reduced headspace volume (MAP fresh salads) or the elimination of oxygen to control mold growth and oxidation. For dried grains, package volume reduction provides optimal utilization of storage space.

2.10 Packaging Equipment Specification

For each food packaging technology, estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Does equipment have vacuum or gas flush capability?	Equipment Mass (kg)	Equipment Volume (m^3)	Power per use (kW)	Water Usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)						
Ground-based (TRL 4)	Both vacuum and gas flush capabilities are available.	94 Kg	0.64 x 0.51 x0.46m = 15 m^3	120 volts/13 amps	None	Manually operated. Cycle time is about 30 sec.

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

The technology is commercial.

2.11 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream

Material/ Technology	Describe Equipment Clean-up	Water usage (liters per cleaning)	Chemical usage	CM-h per clean-up
Vacuum packaging	The sanitation program would most likely be a thorough wipe down with a mild detergent followed by a potable water wipe down and then a wipe down with an environmentally friendly sanitizer.	Minimal	Minimal	30 minutes

2.12 Equipment Lifetime

Describe the expected lifetime of the food packaging equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Vacuum packaging	Very durable, >10 years	Seal wire, vacuum pump, seal bar Teflon tape	Every three months

What relevant compounds and circumstances will degrade the performance of or damage the technology? – Poor maintenance

2.13 System Integration: Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Vacuum packaging	Reduce package volume, reduced food oxidation, control of fungal growth	Fine droplets of vacuum pump oil being dispersed into the atmosphere	Air

2.14 Reliability, Monitoring and Control: What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe packaging reliability	Evaluate packaging risk
Vacuum packaging, High barrier packaging materials for intermediate shelf life	Very reliable if the equipment is maintained in working order.	Must avoid packaging foods that have a potential to support the growth of Clostridium botulinum, if viable spores are present and temperature abuse occurs or foods that may contain vegetative pathogenic bacteria. The risk is food borne illness. Inadequate evacuation of air will result in oxidation of the food – possible decrease in sensory attributes and nutritional value

What sensor data and controls are necessary to insure the packaging equipment is functioning properly? What long term measurements are necessary to insure the functionality of the packaging material? What data processing is needed to relate the sensor data to the control data?

Technology	Type of Sensor Data Needed	Sensor available	Controls needed for process	Data processing needs	Test available to measure quality of packaging material?
Vacuum packaging	Vacuum level, seal time, gas flush time	Yes	Minimal	None	Seal strength, OTR, MVTR, tensile, modulus, elongation @ break, puncture resistance

2.15 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
High barrier packaging materials for intermediate shelf life	Aseptic and retort packaging	Oxygen scavenging packaging	Continual improvement in the film's physical properties and machinability	

2.16 Data Sources

What references and data sources were used in completing this form? Cryovac product specification sheet.

3.0 Food Packaging: Bulk Packaging for dry flowables

3.1 If commercial, state manufacturer and specification or reference number: - Fresco, PrintPack, Cryovac, Curwood

3.2 Current TRL (Refer to Appendix A): 6

3.3 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

3.4 Function: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

<u>Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops. Some food preservation technologies may be used to preserve the processed ingredients.</u>

Heat sealable high abuse, high moisture barrier pre-made thermoplastic bags. The material's durability and moisture vapor transmission rate properties protects the dried food protects against excessive moisture loss during extended storage and product spillage.

Manual or automated equipment for filling and sealing the bag are commercially available. To conserve space, a vacuum source or package compression device could be incorporated into the packaging equipment.

3.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development?

No known hazard when used on earth. To avoid the possibility of the material carrying a potential pathogenic bacteria or other microorganism that could contaminate the crop production and processing areas, the materials could be sterilized by irradiation.

Dust is a significant hazard during filling. Dust must be controlled by keeping the dust enclosed by using a connector – transfer directly into container. A fitment specific for dry flowables is needed. Commercially available from Scholz and FranRica.

3.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)
Bulk Packaging for dry flowables	OTR typically 1,000 to less than 1 cc/m^2	Clear to opaque	0.5 to 0.02 gms/100 in^2	3 to 5 mils in thickness, about 69 to115 gms/m^2	Flexible

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
Bulk packaging for dry flowables	High abuse resistance, High barrier to moisture vapor transmission	Non-biodegradable	1 to 8 depending on the composition	8	High moisture barrier for preventing hydration or dehydration during prolong storage

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
Bulk packaging for dry flowables	Multilayer, multi-constituent thermoplastic films complying with 21 CFR 175.45	None

Temperature limitations of the packaging material:

Material/ Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^{o}C)	Effect of temperature on packaging and food interaction
Bulk packaging of dry flowables	No	Yes	Typical condition of use would be 30^{o} C to <0^{o} C, the actual upper an lower limits are unknown	Typically, for every 10^{o} C increase, the MVTR will double.

3.7 Packaging Design

Technology	How does package design enhance food quality	How has convenience affected the package design?
Bulk packaging of dry flowables	By serving as a barrier to moisture for extended storage applications. Mold growth is inhibited by maintaining a Aw level of less than 0.65.	

3.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for
Bulk packaging of dry flowables	Typically stated as 2 years, maximum has not been determined	9	8	Flexible material not intended to be thermoformed	Dried or processed grains. The products water activity must be below the level that supports fungal growth

3.9 Food Packaging Equipment, Packaging Material Information

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? Unknown

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
Bulk packaging of dry flowables	No known dependence	No known effect

What would prevent the current packaging equipment from being operated upside down in a terrestrial environment? ? Limitations will be loading of the product into the bag.

Equipment Technology	Suitable for ground operations?	Suitable for planetary surface	Unique to one packaging technology? If not, list other technologies with same traits
Bulk packaging of dry flowables	Yes	Unknown	Vacuum packaging could be utilized as a means of reducing the package volume for better storage space utilization. Typically, pre-made pouches would be filled and then sealed with a ban sealer

3.10 Packaging Equipment Specification

For each food packaging technology, estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Does equipment have vacuum or gas flush capability?	Equipment Mass (kg)	Equipment Volume (m^3)	Power per use (kW)	Water Usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)						
Ground-based (TRL 4)	Both vacuum and gas flush capabilities are available.	94 Kg	0.64 x 0.51 x0.46m = 15 m^3	120 volts/13 amps	None	Manually operated. Cycle time is about 30 sec.

3.11 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

For planetary operation, a small vacuum packaging unit would be most applicable for packaging. It could be used to either vacuum and seal or seal only.

Material/Technology	Describe Equipment Clean-up	Water usage (liters per cleaning)	Chemical usage	CM-h per clean-up
Bulk packaging of dry flowables	For dry products, dust control will be the major issue	Minimal	Minimal	Unknown

3.12 Equipment Lifetime

Describe the expected lifetime of the food packaging equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/ Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Vacuum packaging	> 10 years	Seal wire, Teflon tape, vacuum pump, individual controls – sealing, vacumizing	Every 3 months

What relevant compounds and circumstances will degrade the performance of or damage the technology? – Poor maintenance

3.13 System Integration: Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Bulk packaging of dry flowables		Dust pollution during the filling of bags with dry grain products can must be controlled	Air

3.14 Reliability, Monitoring and Control: What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe packaging reliability	Evaluate packaging risk
Vacuum packaging	Commercial technology	Minimal

What sensor data and controls are necessary to insure the packaging equipment is functioning properly? What long term measurements are necessary to insure the functionality of the packaging material? What data processing is needed to relate the sensor data to the control data? No information provided

3.15 Technology Advances – no information provided

3.16 Data Sources – no information provided

4.0 Food Packaging: Liquid Crystal Polymers

4.1 If commercial, state manufacturer and specification or reference number:

Superex Polymers, Inc. Waltham, MA

Dupont, Zenite brand

Amoco, Xydar brand

Ticona, Vectra brand

4.2 Current TRL (Refer to Appendix A): 3

4.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

4.4 Function: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Prepackaged food items with a shelf life of 3-5 years. Post harvest technologies to provide acceptable, safe processed food crops.

Liquid Crystal Polymers (LCP) have exceptional oxygen barrier and high physical property performance compared to standard packaging polymers. LCP are considered engineering polymers thus are mainly too expensive for food packaging applications. Typical commercial applications have LCPs being combined in very small amounts with other materials such as LDPE and PET to gain benefit of their performance, but to minimize total costs. LCPs can be used in film and semi-rigid container designs. Even at $7 per pound it is expected that LCPs will be able to provide a cost savings of 30-40 over EVOH structures of equivalent Oxygen barrier. LCP have better oxygen and water barrier properties than EVOH, MXD6, PVDC, PET, or PEN. They also have greater strength than these other polymers.

Excellent oxygen and moisture barrier. It is a monolayer material which is easier to process through the Solid Waste Management System. It can also be reused more easily since it is a monolayer.

Good structure and can be considered for reusable applications. Semi-rigid material. Packaging material has been used in hot fill and retort processes.

4.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development?

No known hazard associated with the material, but to be most efficient with packaging materials, reusable containers should be considered. Cleaning and sanitation of multi-use containers becomes a potential hazard.

4.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)
LCP film	0.23 cc/m2/24 hr-atm @25 µm		0.17 gm/m2-24 hr-atm @ 25µm	1.4 gm/cc	Applicable to all

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
LCP	High barrier properties and high strength	Unknown	Unknown	Yes	Good resistance to foods

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
LCP	Melt-processable or thermotropic polyesters formed in solution to achieve a high degree of orientation	None known

Temperature limitations of the packaging material

Material/Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^{o}C)	Effect of temperature on packaging and food interaction
LCP	Y	Y	Up to 220	This materials is sterilizable to 135 C

4.7 Packaging Design

Technology	How does package design enhance food quality?	How has convenience affected the package design?
LCP	Because of the exceptional barrier properties LCP can be used component in packaging films or as the substrate for multi-use food containers. In either case, the containers need to be vacuum or gas flushed packaged to remove headspace O2.	Design is not limited by material

4.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for
LCP	9	9	9	7	Dehydrated, frozen and thermostabilized.

4.9 Food Packaging Equipment, Packaging Material Information

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness?

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
LCP	None known	

4.10 Packaging Equipment Specification – no information provided

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Material/Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
LCP	Unknown	Unknown

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

The materials are readily available and well understood. Since cost is not the major concern there could be a process to optimize the barrier properties of the structures containing LCPs. I would also suggest the investigation on multi-use food containers for packaging products grown and processed in space.

4.11 Equipment Clean-up – no information provided

4.12 Equipment Lifetime – no information provided

4.13 System Integration: Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
LCP	LCP when used in films can reduce packaging weights. When used as semi-rigid containers, they can be multi-use with the resulting savings of materials	Multi-use containers will require cleaning and sanitizing.	

4.14 Reliability, Monitoring and Control: What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe packaging reliability	Evaluate packaging risk
LCP	Very good to excellent	Low

What sensor data and controls are necessary to insure the packaging equipment is functioning properly? What long term measurements are necessary to insure the functionality of the packaging material? What data processing is needed to relate the sensor data to the control data?

Technology	Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs	Test available to measure quality of packaging material?
LCP	None				

4.15 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
LCP	Other barrier polymers exist	MAP, Vacuum packaging	Commercial trials being conducted	Optimization of material combinations

4.16 Data Sources

What references and data sources were used in completing this form?

Lusignea, R.W. 1997. Liquid Crystal Polymers: New Barrier Materials for Packaging. Packaging Technology and Engineering, October 1997

http://www.Goodfellow.com/static/e/es31.html

5.0 Food Packaging: Modified atmosphere packaging (MAP) of fresh salads

5.1 If commercial, state manufacturer and specification or reference number: Cryovac, PrintPack, Amcor, Deluxe Packaging

5.2 Current TRL (Refer to Appendix A): 6

5.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

5.4 Functions

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

<u>Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops</u>.

Passive modification of a package atmosphere (MAP) based on the relationship between the oxygen and carbon dioxide transmission rates of the packaging material and the respiration rate of the salad crop can provide a shelf life of 10 to 14 days at a storage temperature 40 F. The technology is widely used in the food service and retail markets. Passive MAP mechanically removes the excess gas from a packaged food. Then the specialized packaging is used to extend the shelf life by minimizing the respiration of the crop. Active MAP gas flushes the packaged food. Both passive and active MAP may only extend the shelf life of the food for a few days. Alternate technology may be to delay harvest and consume as needed. Refrigeration in minimal packaging (such as minimum gauge material and reusable bags such as sandwich or ziplock bags. The bags may be perforated) will provide a 7-day shelf life of <u>intact</u> crop.

The packaging material's gas transmission rates must be appropriately matched with the respiration rate of the salad crop. Shelf life is dependant on food products.

Refrigeration is critical to the success of this application

The general physical properties of the packaging materials are:

Abuse resistance - to minimize the development of pinholes and film rupture during handling

Specific OTR - matched to the product's respiration rate and desired concentration of O_2 and CO_2 package in the package atmosphere.

Heat sealable - to provide a hermetic seal

For small scale packaging operations suitable for a micro-gravity environment, the salad mix would be loaded into pre-made flexible bags. The bags would be sealed using a manually operated vacuum packaging machine or an impulse heat sealer. Vacuum is used to remove a given volume of air from the package.

Success of the application relies on production and post harvest handing practices that minimizes the selection of over-mature product, product damage, microbial contamination (both spoilage and pathogenic bacteria), and exposure to conditions that could accelerate product deterioration. The OTR and CO_2 TR properties must match the respiratory rate of the product at the intended storage temperature (32-40 F).

5.5 Hazard Identification

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development?

The composition of the packaging material must meet the FDA indirect food additive requirements, 21 CFR 174.5.

Potential hazards would be contamination of the finished product with chemicals and pathogenic microorganisms. Advise against extended storage of products in this environment due to changes in spoilage organisms and there is a potential to grow pathogenic microbial flora.

Manufacturing practices of the materials should ensure that the materials are not contaminated with chemical or microbial hazards that could cause a health hazard.

Irradiation treatment of the film can be used to destroy pathogenic and spoilage bacteria. This is not practiced for products packaged for consumption on earth.

5.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)
Modified atmosphere packaging	3,000 cc/m^2 – 16,000 cc/m^2, CO_2TR is approximately 4X the OTR	Clear to opaque	0.5 to 5 gm/100 in^2/day @ 100^o F and 100%RH	At 1.25 mil, about 29 gms/m^2	Flexible bags will probably most applicable because of source and space reduction considerations. Rigid trays with lidding films are available at the expense of twice the space requirement and weight.

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
Modified atmosphere packaging	Thin film technology with high abuse and OTR's ranging from 3,000 cc/m2 to 16,000 cc/m2	Not degradable by microorganisms	1	4	If the OTR is not properly matched to the respiration rate of the fresh salad products, product fermentation can occur.

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
Modified atmosphere packaging	The materials typically consist of polyolefins, polystyrene, ethylene vinyl acetate copolymer and other specialty resins with high OTR properties. All constituents comply with 21 CFR 174.5	Insignificant

Evaluate the Temperature limitations of the packaging material:

Material/ Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^{o}C)	Effect of temperature on packaging and food interaction
Modified atmosphere packaging	Yes	Yes	Most films are stored at temperatures below 40 C. The upper temperature limitation is dictated by whether or not the film is orientated during manufacturing process. Orientation results in shrinkage at elevated temperatures (>40 C).	An increase in temperature will result in a higher respiration rate of the salad product. The gas transmission properties cannot maintain the appropriate oxygen and carbon dioxide concentration. As a result, the package atmosphere becomes depleted of oxygen and product fermentation occurs.

5.7 Packaging Design

Technology	How does package design enhance food quality?	How has convenience affected the package design?
Modified atmosphere packaging	The package atmosphere generated by the product/ package interaction lowers the respiratory rate of the product. This is key to reducing the rate of product senescence and extending shelf life. The MVTR of the packaging material also reduces moisture loss from the product	Easy open features can be applied to eliminate the needs for a sharp cutting object.

5.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for
Modified atmosphere packaging	Typically, 2 years stated. Actual shelf life is unknown.	1	5 to 9	Not designed for thermoforming	Fresh cut vegetables

5.9 Food Packaging Equipment, Packaging Material Information – no information provided

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? - Unknown

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
Modified atmosphere packaging	No known effect	No expected effect

What would prevent the current packaging equipment from being operated upside down in a terrestrial environment? Unknown

Equipment Technology	Suitable For Ground Operations?	Suitable For Planetary Surface	Unique To One Packaging Technology? If Not, List Other Technologies With Same Traits
Modified atmosphere packaging	Yes, a unit for packaging on earth would most likely be a vertical, form, fill, and seal unit	Yes	Vacuum packaging can be used for a variety of products for which a reduce headspace there is a benefit for reducing the package volume. It can be used for many processed foods.

5.10 Packaging Equipment Specification

For each food packaging technology, estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Does equipment have vacuum or gas flush capability?	Equipmen t Mass (kg)	Equipment Volume (m^3)	Power per use (kW)	Water Usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)						
Ground-based (TRL 4)	Vacuum capability is available	94 Kg	0.64 x 0.51 x 0.46 = 0.15 m^3	120 volts/13 amps	None	Total preparation, run time, and clean-up is approximately 45 minutes

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used? – Yes

5.11 Equipment Clean-up – no information provided

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Material/ Technology	Describe Equipment Clean-up	Water usage (liters per cleaning)	Chemical usage	CM-h per clean-up
Modified atmosphere packaging	For planetary use, the sanitation program would most likely be a thorough wipe down with a mild detergent followed by a potable water wipe down and then a wipe down with an environmentally friendly sanitizer.	Minimal if appropriate wipes can be utilized for cleaning and sanitizing	Minimal	30 minutes

5.12 Equipment Lifetime – no information provided

Describe the expected lifetime of the food packaging equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/ Technology	Average equipment lifetime	Replacement or expendable parts and their costs.	Recommended maintenance schedule
Modified atmosphere packaging	At least 10 years with proper maintenance.	Seal wires, lubricating oil, Teflon tape, occasionally a vacuum pump	Every three months

What relevant compounds and circumstances will degrade the performance of or damage the technology? – Poor maintenance

5.13 System Integration: Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential Indirect Benefits	Potential Indirect Detriments	Affects Which Life Support System
Modified atmosphere packaging	Reduced volume packaging	Possibility of oil vapor being exhausted from the vacuum pump	Air

5.14 Reliability, Monitoring and Control: What is the reliability of this technology? What is the risk that the technology does not produce a stable food product? Very reliable technology. Performance of the technology, however, is very dependent upon proper temperature control, product selection and product sanitation.

Technology	Describe packaging reliability	Evaluate packaging risk
Modified atmosphere packaging	Used commercially for a variety of fresh and processed foods.	Minimal. It is not a technology that provides any growth inhibition of pathogenic bacteria.

What sensor data and controls are necessary to insure the packaging equipment is functioning properly? What long term measurements are necessary to insure the functionality of the packaging material? What data processing is needed to relate the sensor data to the control data?

Technology	Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs	Test available to measure quality of packaging material?
Modified atmosphere packaging	Vacuum level, gas flush time, and heat sealing parameters	Yes	Vacuum level, gas flush time, and heat sealing parameters	None	Tensile, modulus, elongation at break, seal strength, OTR, MVTR, impact strength

5.15 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
	Controlled atmosphere storage has the potential to provide additional shelf life beyond that which can be delivered with MAP. It is more beneficial to fruits than MAP but more complex.		New material formulations to improve the functionality of the packaging material.	

5.16 Data Sources

What references and data sources were used in completing this form? Cryovac technical data sheets for produce packaging materials and equipment

6.0 Food Packaging: Ultra-high oxygen barrier film based on oxygen scavenging

6.1 If commercial, state manufacturer and specification or reference number: Cryovac

6.2 Current TRL (Refer to Appendix A): 3

6.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

6.4 Functions

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Prepackaged food Items with a shelf life of 3 – 5 years that are safe, acceptable and provide the correct nutrition. This technology is independent of food. It will work with dry or moist products. In other words, the oxygen scavenger can work for any food.

Foil based pouches for retort products are susceptible to flex cracking that can result in an increase in oxygen permeability of the pouch. The combination of a foil laminate oxygen barrier retort pouch and an oxygen scavenging over-wrap provides a package that will compensate for any flex cracking. The oxygen scavenging over-wrap would be applied after the retort process using gas flush packaging technology.

The oxygen scavenging process is activated prior to the packaging the primary retort package. Combine with foil packaging to reduce overwrap. Sensory changes influenced by polymer degradation (may experience flavor of packaging into food).

Foil laminate or metalized film are commercially available and being used for military MREs. This document discusses the oxygen scavenging technology.

This technology currently has only been tested for hot fill but should work for other preservation methods such as thermally processed or microwave application.

6.5 Hazard Identification

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

One hazard could be post-processing contamination of the packaging material with pathogenic bacteria. This concern could be addressed through GMP's, HACCP, and post packaging irradiation, and sanitizers.

Packaging will consume oxygen at continual rate on exterior of pouch – trivial rate.

Do not know if there would be off-gassing in an enclosed environment.

Iron oxide, used as the oxygen scavenger, needs protection from water and oxygen. If use in a sacher, it may generate hear and off-gas once activated.

6.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)
Ultra-high oxygen barrier film based on oxygen scavenging	< 0.001 with the scavenger activated	Opaque at 290 nm	0.24 gm/100 in^2 at 38^o C, 90% RH	At 2.5 mils, about 58 gms/m^2	Flexible

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
Ultra-high oxygen barrier film based on oxygen scavenging	Ultra high oxygen barrier package	Non-biodegradable	3	1	By maintaining the food in an environment free of oxygen, oxidation of the food product is minimized.

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
Ultra-high oxygen barrier film based on oxygen scavenging	Multiple layer, multi-constituent film, all constituents comply with 21 CFR 174.5	No known concerns

Temperature limitations of the packaging material

Material/ Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^{o}C)	Effect of temperature on packaging and food interaction
Ultra-high oxygen barrier film based on oxygen scavenging	N	Y	The film has not been evaluated at extreme temperatures. Commercial applications are room temperature and below.	No interaction is expected within the temperature storage range for foods.

6.7 Packaging Design

Technology	How does package design enhance food quality?	How has convenience affected the package design?
Ultra-high oxygen barrier film based on oxygen scavenging	The oxygen scavenging over-wrap excludes the food product from exposure to oxygen. This minimizes product oxidation	The convenience feature is the ability to activate the oxygen scavenging system on demand. Iron based oxygen scavengers must be protected from oxygen and moisture until they are ready to be used. Activation on demand is a convenience for the processor.

6.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for
Ultra-high oxygen barrier film based on oxygen scavenging	Unknown	9	8	Not designed for thermoforming	All foods that are susceptible to oxidation

6.9 Food Packaging Equipment, Packaging Material Information

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness?

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
Ultra-high oxygen barrier film based on oxygen scavenging	No known dependence	No known effect

What would prevent the current packaging equipment from being operated upside down in a terrestrial environment?

For most automated, high volume output machines, it would be size and complexity. For this technology, these would be pre-packaged products prepared on earth for extended shelf life.

Equipment Technology	Suitable for ground operations?	Suitable for planetary surface	Unique to one packaging technology? If not, list other technologies with same traits
Horizontal gas flush flow wrappers.	Yes	No	

6.10 Packaging Equipment Specification (for Mars surface) – no information provided

For each food packaging technology, estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

There are several equipment suppliers for these systems. Ulma and Illapak are suppliers. Need single vacuum chamber. To activate scavenger, need high intensity UV light at 244 nanos.

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

The technology is applicable to prepackaged foods prepared on earth for extended shelf life. The oxygen scavenging and flexible retort packaging materials are available for validation in a relative environment.

6.11 Equipment Clean-up – no information provided

6.12 Equipment Lifetime – no information provided

6.13 System Integration: **Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.**

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Ultra-high oxygen barrier film based on oxygen scavenging		The oxygen scavenging process must not deplete the oxygen level in the vehicle.	Air

6.14 Reliability, Monitoring and Control: What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe packaging reliability	Evaluate packaging risk
Oxygen scavenging film based on oxygen scavenging film	The reliability is established for refrigerated pasta and ambient temperature beef jerky.	If the film does not scavenge, shelf life reduction could occur if the primary package was permeable to oxygen as a result of flex cracking or an elevated OTR property. There would be no food safety risk. Scavenger has not been evaluated for thermally processed foods.

What sensor data and controls are necessary to insure the packaging equipment is functioning properly? What long term measurements are necessary to insure the functionality of the packaging material? What data processing is needed to relate the sensor data to the control data?

Technology	Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs	Test available to measure quality of packaging material?
Oxygen scavenging film based on oxygen scavenging film	Absorbed UV dose – UV light is used to activate the oxygen scavenging process. Indicator to show that the scavenging process has been activated.	Both sensors are available from Cryovac		Test available to measure quality of packaging material? OTR of the activated film, oxygen scavenging capacity, tensile, modulus, seal strength, elongation @ break	

6.15 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Ultra-high oxygen barrier film based on oxygen scavenging	There are iron based oxygen scavengers that or incorporated into a plastic film or tray or sachets. The Cryovac system is a polymer based scavenger that is activated on demand. Iron based scavengers are activated when exposed to air and moisture.		Improved scavenging performance.	

6.16 Data Sources Cryovac data

7.0 Food Packaging: AEGIS Nanocomposite Barrier Resins

7.1 If commercial, state manufacturer and specification or reference number: Honeywell Plastics, Aegis OX

7.2 Current TRL (Refer to Appendix A): 3

7.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

7.4 Function: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

<u>Prepackaged food items with a shelf life of 3-5 years that are safe, acceptable and provide the correct nutrition.</u>

Aegis™ OX polymerized nanocomposite, oxygen-scavenging barrier nylon resin - specially formulated for high oxygen and carbon dioxide barrier performance, even in high humidity - is commercially available for a host of co-injection molded PET bottle applications, including bottles and orange juice containers.

Another grade, Aegis NC, can be used as a coating or as the base resin for cast or blown films. Aegis NC does not possess the oxygen scavenger present in Aegis OX. The major application for Aegis NC coatings will be as a replacement for nylon 6 coatings in paperboard juice cartons. Aegis NC provides the cartons with approximately 3 times better oxygen barrier of nylon 6, greater rigidity for less bulging, and is less hygroscopic. In films, Aegis NC can be used as a nylon replacement for process meat and cheese packaging.

The new family of resins nearly doubles the heat resistance of nylon 6 and increases tensile modulus, flexural modulus and flexural strength by 30 to 50 percent allowing the design of thinner, lighter and better performing parts.

Potential less flavor and odor scalping. Possible candidate for high barrier shelf stable foods. Easier to incinerate. May be able to decrease weight and mass.

Move toward all polymer and away from foil.

7.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development?

No Known Hazards associated with this material.

7.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)
Aegis OX	(Oxygen) 0.001/cc/100 in2/atm/day/ @80% RH, 25 C	Clear	Unknown	1.14 g/cm^3	Semi-rigid and flexible

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
Aegis OX	Very high Oxygen barrier	Unknown	Unknown	Yes	Oxygen barrier properties similar to glass.

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
Aegis OX	Proprietary nanocomposite nylon 6 resin	Unknown

Evaluate the Temperature limitations of the packaging material

Material/Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^oC)	Effect of temperature on packaging and food interaction
Aegis OX	Y	Y	Tm= 209 C	Unknown

7.7 Packaging Design

Technology	How does package design enhance food quality?	How has convenience affected the package design?
Aegis OX	High barrier semi-rigid containers possible	Many designs are possible, but semi-rigid plastic makes more convenient

7.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for
Aegis OX	Unknown	9	7	7	Dehydrated or thermostabilized

7.9 Food Packaging Equipment, Packaging Material Information

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness?

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
Aegis OX	None	None

7.10 Packaging Equipment Specification – no information provided

For each food packaging technology, estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Material/Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
AEGIS OX	2,000	$3 – 5 MILLION

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

Validation of manufacturer's claims and specific application trials.

7.11 Equipment Clean-up - no information provided

7.12 Equipment Lifetime - - no information provided

7.13 System Integration: Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Aegis OX	Reusable container		Waste management

7.14 Reliability, Monitoring and Control: What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe packaging reliability	Evaluate packaging risk
Aegis OX	Good	Minimal

7.15 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Aegis OX	Yes	Gas flushed head space	Corporate development	Verification of claims

7.16 Data Sources

What references and data sources were used in completing this form?

Literature from the manufacturer, http://www.honeywell-plastics.com/aegis/aegis.html

8.0 Food Packaging: Triton Nanocomposites

8.1 If commercial, state manufacturer and specification or reference number: no information provided

8.2 Current TRL (Refer to Appendix A): TRL 2

8.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

8.4 Function: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Polymer Nanocomposites can achieve a lower O_2 and H_2O permeability to achieve a 3-5 year shelf life. These materials have already shown to have sufficient barrier to achieve a >3 year shelf life without refrigeration in Army Steam Table Trays. There also exists the possibility of reducing the weight of a given packaging system due to the increased barrier and strength (increased rigidity) achieved by the nanocomposites.

Nanosilicate fillers into thermoplastic polymers can improve the strength and barrier over their unfilled counterparts. No unique requirements - the polymers can be processed by the same method as the unfilled – i.e. extruded, blown film, thermoformed, etc.

Could improve oxygen barrier properties to compete with foil. Moisture vapor transfer rate (MVTR) is not necessarily improved when combined with other materials and may even be worse. Barrier properties dependent on thickness of material, not composition. Have the same properties of a polymer. There is no FDA approval but is under test at Natick Labs. May be good for semi-rigid containers to improve barrier properties.

Combine with EVOH to obtain good oxygen barrier.

Can be reused – nanocomposites are better for this than other materials. Could be reused as a fuel or could be remolded into spare parts or other items.

8.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development?

The nanocomposite fillers do not pose any special threat. In one case, they have achieved FDA approval for food contact, but this is not generally the case. The use of nanocomposite polymers is suggested to be as the outside or middle layer of a multilayer packaging system (not food contact). Extraction tests at US Army research labs in Natick, MA showed that there is no unusual extractables from the nanocomposites as compared with the unfilled polymers.

8.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)
Nylon Nano	1.3	Poor			Semi
EVOH E Nano	0.2 (0%RH) 0.35 (100%RH)	Good			Flexible
CPET Nano	3	Good			Semi

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
Nanocomposites	Same properties as unfilled polymer	None	4 (recyclable, but is mixture of multilayer)	9	

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
Nanocomposites	Polymer, layered silicate fillers	Have tested these for offgassing at US Army – no problems. Have not been FDA approved for food contact

Temperature limitations of the packaging material

Material/ Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^{o}C)	Effect of temperature on packaging and food interaction
Nylon Nano	Y	Y	? to 130	
EVOH E Nano	Y	Y	? to 80-100	
CPET Nano	Y	Y	? to 70-100	

8.7 Packaging Design – no information provided

8.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent. – no information provided

8.9 Food Packaging Equipment, Packaging Material Information

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness?

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
All polymers	Unknown	Unknown

8.10 Packaging Equipment Specification

For each food packaging technology, estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

I don't have a grasp on the equipment necessary – the nanocomposites would be processed in the same method as with conventional polymer processing equipment.

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Material/Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
Nanocomposites	After phase I SBIR is complete, phase ii time and money is planned to bring the technology to TRL=5,6. I estimate production and evaluation of multilayer film incorporating nanocomposites at TRL=5 to be about a 6 month (~1000 hour) $100k effort.	

8.11 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Material/Technology	Describe Equipment Clean-up	Water usage (liters per cleaning)	Chemical usage	CM-h per clean-up
Nanocomposites	No difference than typical polymer processing equipment			

8.12 Equipment Lifetime

Describe the expected lifetime of the food packaging equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Nanocomposites	No difference than typical polymer processing equipment		

8.13 System Integration – no information provided

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

I don't see any benefits or detriments with these materials.

8.14 Reliability, Monitoring and Control: What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe packaging reliability	Evaluate packaging risk
Polymer Nanocomposites	Has shown improvements in barrier on large-scale production. Materials process and perform (mechanical and processibility) as well as or better than the unfilled polymer films.	Have not been assessed for long term stability yet. Thermoformed trays are currently being evaluated for long term stability on an US Army program

8.15 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Nanocomposites	High Barrier Coatings (i.e. PPG epoxy)		Government funded programs exist for improvement of O_2 / H_2O barrier by dispersion of nanoparticles in plastics – some basic research, some applied packaging studies	Evaluation of materials on prototype multilayer packaging incorporating nanocomposite materials – industrial scale production – not only lab scale

8.16 Data Sources

What references and data sources were used in completing this form?

www.matweb.com

9.0 Food Packaging: PET with Oxygen Scavenger

9.1 If commercial, state manufacturer and specification or reference number: Amcor North America

9.2 Current TRL (Refer to Appendix A): 3

9.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

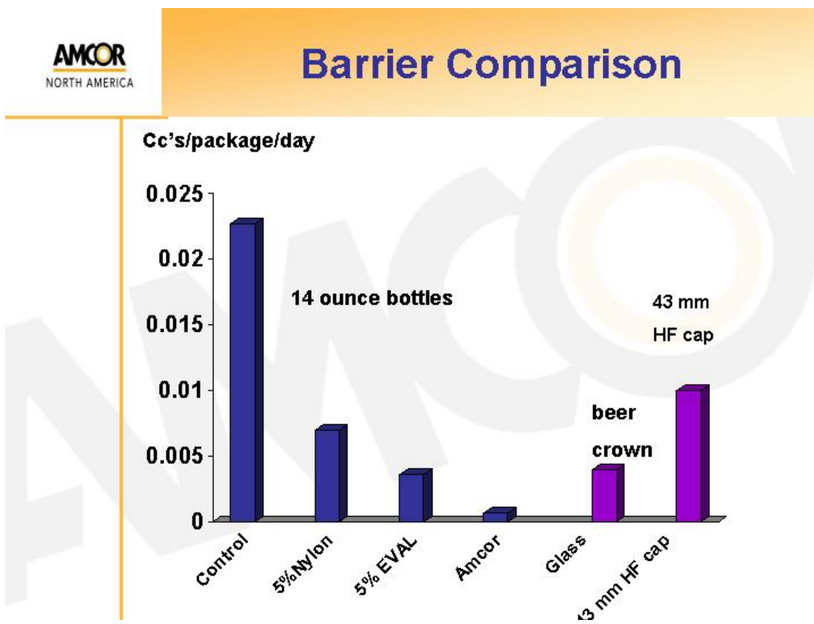
☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

9.4 Function: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Prepackaged Foods with a shelf life of 3-5 years that are safe, acceptable and provide correct nutrition.

Amcor North America is promoting a proprietary blend of PET that would have better oxygen barrier properties than glass or EVOH blend containers. It can only be assumed the improved barrier properties over glass result from an improved closure system and not the use of beer crown closures. If indeed the barrier properties are correct, then strong, lightweight containers are possible. It is even possible that they might be reusable. Suitable for low moisture, hot fill foods.



9.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development?

No known hazards

9.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)
Amcor PET	Oxygen= 0.0007 cc/package/day	Excellent	Unknown	Similar to PET	Semi-rigid

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
Amcor PET	7	Unknown	Unknown	Yes	8

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
Amcor PET	PET	Unknown

Temperature limitations of the packaging material

Material/Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^oC)	Effect of temperature on packaging and food interaction
Amcor PET	Y	Y	To 200 C	Unknown

9.7 Packaging Design

Technology	How does package design enhance food quality?	How has convenience affected the package design?
Semi-rigid container	High barrier resin combined with barrier closure to give desired shelf life	A semi-rigid container can be made which is more convenient than a flexible

9.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for
Amcor PET	Unknown	9	8	8	Dehydrated and thermostabilized

9.9 Food Packaging Equipment, Packaging Material Information

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness?

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
Amcor PET	None	none

9.10 Packaging Equipment Specification – no information provided

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Material/technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
Amcor PET	2,000	$3 – 5 million

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

Validation of manufacturer's claims and specific application trials.

9.11 Equipment Clean-up – no information provided

9.12 Equipment Lifetime – no information provided

9.13 System Integration: Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Amcor PET	Reusable container		Waste management

9.14 Reliability, Monitoring and Control: What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe packaging reliability	Evaluate packaging risk
Amcor PET	Good	Minimal

9.15 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Amcor PET	Yes	Gas flushed head space	Corporate development	Verification of claims

9.16 Data Sources

What references and data sources were used in completing this form?

Literature from the manufacturer,

Amcor PET Packaging - North America
910 Central Parkway West, Mississauga
Ontario L5C 2V5, Canada
Tel: +1 (905) 275-1592 Fax: +1 (905) 275-1061

10.0 Food Packaging: Odor absorbent packaging

10.1 If commercial, state manufacturer and specification or reference number:

10.2 Current TRL (Refer to Appendix A): 2

10.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

10.4 Function: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

<u>Prepackaged food items with a shelf-life of 3-5 years that are safe, acceptable and provide correct nutrition</u>

During thermal processing and extended shelf life storage the quality of many food and beverage products are compromised by low molecular weight carbonyl compounds. Many of these compounds are degradation products produced by thermal processing. Low molecular weight carbonyl compounds in foods and beverages can also be attributed to the release of these compounds from packaging materials. The addition of sequestering agents specific for off-flavor compounds inclusive with a carbonyl functional group may improve the overall quality of many food and beverage products. The active agents included in these polymer blends will preferentially react with carbonyl compounds and form high molecular weight complexes.

Active packaging systems, which remove or “scalp” gases, by adsorption or absorbent, have been previously reported in scientific literature and patent applications. The focus of most of these packaging systems has been oxygen and ethylene removal (Zagory 1995;Teumac 1995;Rooney 1981;Rooney 1995; Brody and Budny 1995; Field et al. 1986; Smith et al. 1986). The use of active packaging systems to selectively remove off-flavor compounds and improve the flavor quality of foods is a new idea. Most of the current research in this area is limited to the removal of flavor compounds by unmodified native polymers based on polarity (Lebosse et al., 1997: Feigenbaum et al., 1998). The removal of flavor compounds based on chemical functional groups is limited to amines and sulfur containing compounds (Rooney 1995).

The addition of polymeric amines to thermoplastics is reported to remove low molecular weight aldehydes such as acetaldehyde. Acetaldehyde is an undesired byproduct formed during the polymerization and melt processing of polyesters. Polymer companies have made an effort to reduce the amount of acetaldehyde in food beverage containers due to the deleterious effect it has on the flavor of sensitive beverages such as milk, cola, beer, and water. Eastman Chemical Company has proposed a multilayer poly(ethylene terephthalate) (PET) package inclusive with an acetaldehyde reducing additive through co-extrusion (Long et al. 2000; Nelson et al. 2000; Mills and Stafford 1993). A middle polyamide layer is added to remove acetaldehyde from the two PET layers by forming a reduced acetaldehyde polyester.

While researchers have looked at active compounds to remove undesirable acetaldehyde from polyester polymers, it has not been used to remove low molecular weight ketones from beverages and foods such as UHT processed milk. Ketones, like aldehydes, contain a functional carbonyl group that readily reacts with amines.

Depending upon the surface area required to achieve the effective removal of off-flavor compounds, the active portion of the beverage container may be limited to the closure. Limiting this technology to the closure would decrease the cost of the package and place the active portion of the package at the headspace where most volatile compounds are concentrated. The use of polymeric amines in packaging to remove volatile food components may be an effective means to remove unpleasant flavor notes.

Another effective approach to remove unpleasant flavor notes typical of UHT processed milk may be to incorporate starch blends with synthetic polymers in food packages. The use of cyclodextrins in cleaners and polymers to remove odors has been demonstrated by various researchers (Trinh and Phan, 1998;Sivik et al., 2000). Commercial applications of this technology include Febreeze® Fabric Cleaner and Glad® Odor Shield trashbags. These applications incorporate non-specific odor absorbing compounds. Odor-controlling agents that have been added to cyclodextrin include: silicate/aluminate zeolite, activated carbon, fibrous absorbent material, absorbent gelling material, absorbent foam, and absorbent sponges. Hypothetically, active agents that form large impermeable compounds with low molecular weight carbonyl compounds may be incorporated in cyclodextrins in a polymer packaging system. Potential active agents include polymeric amines and other previously mentioned compounds.

Can be used in combination with high barrier packaging. It is usually put in the primary layer. It is not stand-alone. Can also be used for solid waste and dirty clothes to reduce odor.

10.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development?

No known hazards

10.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)
Odor absorbent polymer	Dependent upon base polymer				Can be flexible or semi-rigid

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
Odor absorbent polymer	Removes undesirable food odors	Unknown	Unknown	Unknown	Removal of odors associated with oxidation should improve sensory qualities

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
Odor absorbent polymer	PET or HDPE with Nylon 6, Sorbitol, Cyclodextrin	Unknown

Evaluate the Temperature limitations of the packaging material

Material/Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^{o}C)	Effect of temperature on packaging and food interaction
Odor absorbent polymer	Y	Y	Base polymer dependent	Unknown

10.7 Packaging Design

Technology	How does package design enhance food quality?	How has convenience affected the package design?
Odor absorbent polymer	Combined with high barrier polymers this could improve shelf life	

10.8 Packaging Material Stability: Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for
Odor absorbent polymer	Base polymer dependent				

10.9 Food Packaging Equipment, Packaging Material Information

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness?

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
Odor absorbent polymer	None	None

10.10 Packaging Equipment Specification – no information provided

For each food packaging technology, estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Material/Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
Odor absorbent polymer	Unknown	Unknown

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

This technology is in the exploratory stages. The concept of odor removal has been proven, but will the removal compounds be sufficiently selective to remove the off-odors and not remove desirable aroma compounds.

10.11 Equipment Clean-up – no information provided

10.12 Equipment Lifetime – no information provided

10.13 System Integration – no information provided

10.14 Reliability, Monitoring and Control – no information provided

10.15 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Odor absorbent polymer	Yes, but not for food applications	Barrier polymers	Active research program at Virginia Tech	

10.16 Data Sources

What references and data sources were used in completing this form?

Part of an active research program at Virginia Tech

11.0 Food Packaging: Edible Film for Food Packaging

11.1 If commercial, state manufacturer and specification or reference number:

11.2 Current TRL (Refer to Appendix A):

11.3 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

11.4 Function: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

The areas of edible and biodegradable packaging do not currently meet the 3 – 5 year mission constraints. The best edible films are at least 100 times less effective in gas barrier properties than the worse polymers.

The best materials contain lipids. Cannot be used with processing systems or most systems. Cannot retort or hot fill. The high temperature will breakdown the material. In addition, the biodegradable properties of the film will also mean that the material will begin degrading over time even with the food contained in it. With the potential deterioration of the packaging material, there are safety issues of the packaging. Since it may break down and is therefore unreliable, the food may not maintain safety.

Producing edible films will require raw materials and compete with food supply. In other words, the resources and materials will compete with food supply.

11.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development?

Producing plastic polymer films on a planetary surface is not a viable option because of concerns with generating unsafe gasses, weight/volume of the equipment and polymer supplies, and limited recyclability or reuse of laminate structures. Producing edible films on a planetary surface would likely tie up resources needed elsewhere, and functionality of edible films produced on a planetary surface will not meet mission constraints. Producing packaging materials from a waste stream would possibly require less ESM. One option would be to produce packaging materials from lignin; however, there might be too many hazards associated with producing lignin packages, and the functionality of this product may not meet mission requirements. A more viable option seems to be sending up pre-formed pouches that only require filling, sealing, and thermal processing.

11.6 Material Physical Factors - no information provided

11.7 Packaging Design - no information provided

11.8 Packaging Material Stability - no information provided

11.9 Food Packaging Equipment, Packaging Material Information -no information provided

11.10 Packaging Equipment Specification -no information provided

11.11 Equipment Clean-up – no information provided

11.12 Equipment Lifetime – no information provided

11.13 System Integration --no information provided

11.14 Reliability, Monitoring and Control -no information provided

11.15 Technology Advances -no information provided

11.16 Data Sources -no information provided

Technology Assessments: Food Preservation

1.0 Food Preservation: Conventional Thermal Processing – Retort (air-overpressure) or Rotomat (water overpressure) of low acid and acid foods

1.1 If commercial, state manufacturer and specification or reference number:

Various manufacturers for standard retorts.

1.2 Current TRL (Refer to Appendix A):

Earth Ops Pre-Mission 9

Mission Ops 5

Technology is proven (retort pouches/cans/jars) to manufacture sterile food products of 3-5 year shelf life. This technology could be used to manufacture prepackaged food items for the transit vehicle and surface habitat lander. Would need to develop a system that utilizes this technology for an evolved Mars base, but development will be simple.

1.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

1.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

This is a standard processing technology used today to render low acid food products free of pathogens and spoilage microorganisms and enzyme activity. Such processed products are commercially sterile. Technology could be extended to achieve complete sterility, if necessary. Developed food items are filled into cans, retort pouches or jars and then processed with air-overpressure or water-overpressure for specified times and temperatures. Retort pouch applications (versus can or jar) would be more desirable for the mission due to packaging/volume constraints.

For prepackaged food items manufactured on Earth, the technology exists . The items would be ready-to-eat (MRE) or heat-and-serve applications. Package sizes could range from individual to multiple servings.

For an Evolved Mars Base, a scaled-down version of the equipment would be necessary. Thermal process testing of the system in microgravity and hypogravity environments may be necessary to validate time/temperature heating parameters. Such a system would allow for preservation of some harvested crops beyond their normal shelf life. Acceptability of the foods after processing would need to be evaluated. System could potentially be used in transit to heat foods.

Packaging equipment for the retort pouches would also need to be developed for a scaled-down system. Replacement parts (e.g., seal jaws) would need to be available as they wear out over time.

1.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

The “low acid food regulations” (21CFR part 113) explains the hazards associated with thermal processing of low acid foods. All relate to ensuring the proper time/temperature relationships are developed and maintained during the processing of the food to ensure commercial sterility. Hazards would include: initial product temperature (and time at that temperature – incipient spoilage), product viscosity, product weight, headspace requirements, processing temperature and time, proper functioning of valves during processing (no air entrapment in retort), package seal or seam integrity, time/temperature of product during cooling phase.

Adequate safety features have been incorporated into the technology to control the hazards. The hazards could be lessened further by more automation of the system (with sensors to monitor the various control points).

For a mars based operation, the microbiological hazards associated with the environment of mars must be evaluated before proper processing parameters of foods on mars can be established.

Operational hazards: potential touch temperature hazards and potential hazards with steam venting.

1.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Thermal Processing - retort or rotomat	Storage temperature dependent. Approx. 6 months @100F. Approx. 3 years @ 80F; 5 + years at refrigerated temperatures	Recommended refrigerated to ambient (70 – 80F); freezing temperatures not recommended for retort pouch	Doesn't matter for product. Potential negative effect of high humidity on packaging material.	Package integrity must be verified for off-nominal pressures	Retort pouch; jars; cans, poly-trays. Other materials potentially available with further research.

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

The quality of the food, not the safety, will be impacted by storage time and temperature. While this technology will provide a safe, commercially sterile food, higher temperature and longer time will lower the quality of the product.

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

Packaging films that contain oxygen barriers may serve to extend the acceptable quality shelf life of the foods. A more permeable package will reduce the shelf life and lead to degradation (rancidity development) of some food products. In general permeable packaging will be less effective for these types of products (containing higher moisture). A more permeable package would be acceptable for low moisture foods, but such foods probably would not be processed by this thermal process technology.

1.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food	6-7	6-7	6-7	6-7	5-7

1.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life
Thermal processing – retort or rotomat	Retort process is not gravity dependent, but rotomat is gravity dependent. Equipment would require some re-design for microgravity use	Unknown, but processing parameters would have to be verified if used in micro/hypo-gravity

1.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)	50 kg	1.0 (Assume: 12 liters product/cycle)	1.4 kW-hours, 3 kW	1.0	4 hours per batch process (includes preparation of product and package filling)
Ground-based (TRL 4)	Not applicable				

Theoretical (TRL 2???): Usage estimated for Mars based version of technology. Ground based values are not applicable.

Can the equipment be automated? To what degree?

Much of the equipment is already automated on the Earth-based system. A scaled down version for an Evolved Mars Base would utilize current automation, and further develop automation (sensors) for monitoring and controlling times/temperatures.

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Technology is not texture dependent. However, excessive processing will result in a change of texture that, if to an extreme, may be undesirable.

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

These numbers are based on currently available bench-top systems.

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
Retort or rotomat	3 – 5 MYE	300-500K

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

The issues to be resolved for this technology are reduced gravity/pressure operations, especially pressure control, water recovery and pressurized system hazards. Additional technical issues would involve developing acceptable food products with the available ingredients.

1.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Material/ Technology	Describe equipment clean-up	Water usage (liters per cleaning)	Chemicals used for processing	CM-h per clean-up
Rotomat	Unless a pouch breaks during processing, no clean up of equipment	n/a	Not required	none

1.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/ Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Thermal Processing – retort or rotomat	Physical retort would be decades. Sensors, valves, seals and hoses may be 3-5 years	Sensors – temperature and pressure, cost ? Valves – cost ?	
Packaging system for retort pouches	Seal jaws/ seal tape for pouches would depend on usage. Should last 1-2 years with nominal use	Seal jaws for packaging equipment, cost ?	

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Routine equipment maintenance should prevent degradation of the performance of the equipment.

1.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Thermal processing – retort or rotomat	Process heat is generated could be captured and used in facility. Equipment could potentially be used for biohazard destruction/sanitation and re-heating of packaged products		

1.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Retort or rotomat	Excellent reliability	Low risk if procedures are followed

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature, time and pressure data	Yes	Automated monitoring of process at each of critical control points	Computer monitor and backup – will compare accumulated data with known process program

1.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Thermal process – retort or rotomat	There are other technologies that can provide thermal processes, UHT processing, High pressure processing, ohmic heating	Advances in sensor data acquisition. Potential advances in packaging materials that are compatible with this process	Unknown. Work will need to done to develop a smaller version of the equipment acceptable for an Evolved Mars Base	

1.15 Data Sources

What references and data sources were used in completing this form?

Self knowledge of process.

2.0 Food Preservation: Thermal Processing – Hot Fill & Hold

2.1 If commercial, state manufacturer and specification or reference number:

Commercial systems exist from many manufacturers. These systems could be used to manufacture prepackaged foods for transit. Scale model systems or systems adapted to hypogravity may need to be developed for an Evolved Mars Base.

2.2 Current TRL (Refer to Appendix A): 3

Technology exists. Adaptation to hypogravity would need to be developed.

2.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

2.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

This technology is geared to acidified foods processed to a commercially, shelf stable condition. Prepackaged products in flexible pouches could be manufactured for all missions. An Evolved Mars Base could use the technology for post-harvest processing to a shelf stable condition.

The technology requires acidification of the foods to less than pH 4.6 for processing. It is not usable for low acid foods due to inadequate temperatures for bacterial spore destruction.

2.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Microbial issues with inadequate processing would be a primary hazard. This could result from improper processing temperature or time, or pH control. Safety features monitoring each of these variables would control the hazard. A scaled version of an existing commercial system could have appropriate controls developed.

2.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Thermal Process – HFH	5 years	Frozen to ambient	Doesn't apply	Doesn't apply	Flexible pouch

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Dependent on the food item. Some food items are more susceptible to rancidity development if they contain oils or fats. Oxygen impermeable packaging or storage in oxygen-free environments would control this issue.

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

A more permeable material is less desirable, unless the finished product was stored in the absence of oxygen (e.g., nitrogen atmosphere, or vacuum).

2.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food	7	8	8	8	7

2.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life
Thermal Process – Hot fill & Hold	Would need to be positively circulated through heat tubes. Earth-based systems are gravity fed or use positive displacement pumps	Unknown, but shouldn't have an effect.

2.9 Processing Equipment Specifications – no information provided

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

Can the equipment be automated? To what degree?

A scale model system should be able to be automated except for input of the primary food material to be processed and the collection of the finished product. Such a system would need to be developed, but the technology for such does exist.

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Texture isn't an issue.

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

Don't have information to calculate these numbers.

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
Thermal Processing – Hot Fill & Hold	Significant for system development	Significant for system development

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

Technology exists. Just need to scale down the system to work in a hypogravity environment. Also need to ensure a closed pipe system, with positive product displacement, adequate monitoring of times, temperature and pH, and packaging.

2.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Material/ Technology	Describe equipment clean-up	Water usage (liters per cleaning)	Chemicals used for processing	CM-h per clean-up
Hot Fill & Hold	Would need to flush the system with water and sanitizer to clean	Unknown, system needs to be developed	Some type of equipment sanitizer would be needed	Unknown, system needs to be developed

2.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Hot Fill & Hold	Decades	Sensors, valves, pumps. – cost would be minimal	Unknown until system is developed

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Lack of preventative maintenance.

2.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Thermal process – hot fill & hold	Capture heat to use in facility		

2.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Thermal Process – Hot fill & Hold	Excellent	Low risk

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature and pH	Yes	Monitoring of time, temperature and pH of process	Data acquisition device to monitor critical control points

2.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Hot fill & Hold	Yes, other thermal process technologies	Engineering expertise on miniaturization of commercial systems; Wireless transfer of data signals.	Unknown	

2.15 Data Sources

What references and data sources were used in completing this form? Self knowledge

3.0 Food Preservation: Modeling thermal processing optimization

3.1 If commercial, state manufacturer and specification or reference number:

3.2 Current TRL (Refer to Appendix A): 4

3.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

3.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

The objective is to develop an innovative technology that dovetails our current effort on eliminating pathogens from packaged ready-to-eat meat and poultry products, ensure the quality of the products, and extend shelf life.

As an additional option to the products such as potential space meat and poultry products where normal pasteurization is not suitable to retain product quality, this technology provides a viable solution to the meat and poultry products for astronauts in space. The meat or poultry products treated via this technology will increase the product shelf life tremendously and at the same time to ensure food safety and retain product quality. This technology will be a breakthrough for American meat and poultry processors in improving the food safety of packaged ready-to-eat deli products. Once developed, the technology should be applicable to other crops.

3.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

It is expected that these technologies will be used on Earth. Hazardous concerns will be relating to low steam pressure (< 15 psi), low pressure nitrogen (< 15 psi), and vacuum (1 bar).

3.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Modeling thermal processing optimization	1 year for meat or poultry >3 for other crops	4°C	Ambient	Normal	Barrier films

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Not recommended for meat and poultry products. But, if used for other crops, shelf life should not change.

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

Not recommended.

3.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food					
Processed Food	9	9	9	9	9

3.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment? Unknown

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life
Modeling thermal processing optimization	Not expected	Not expected

3.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)	5 or less	1 or less	<1	5 or less	0.2 or less
Ground-based (TRL 4)					

Can the equipment be automated? To what degree?

Can be completely automated.

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

No requirement.

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

Estimated

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
Modeling thermal processing optimization	1,000	100,000

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)?

Need pilot validation.

Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

This technology is for developing products and processes that will satisfy NASA's food needs for space exploration and habitation while at the same time benefiting the public. The technology will allow us to combat bioterrorism and eliminate pathogens from packaged ready-to-eat meat and poultry products. This technology will be used to increase shelf life of packaged ready-to-eat meat and poultry products to ensure food safety and retain product quality. The developed technology should be also applicable to other crops.

3.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Material/Technology	Describe equipment clean-up	Water usage (liters per cleaning)	Chemicals used for processing	CM-h per clean-up
Modeling thermal processing optimization	No requirement	No specific requirement	No	No requirement

3.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Modeling thermal process optimization	>5	seals, values, < $200	yearly

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Unknown

3.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Modeling thermal processing optimization	Not expected	Not expected	Unknown

3.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Modeling thermal processing optimization	Expected to be reliable	Not expected

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Pressure and vacuum gauge	Yes	Solenoid values	Acquisition system

3.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Modeling thermal processing optimization	Technologies relating to thermal food processing	Pasteurization and packaging system	Lab testing	Pilot validation

3.15 Data Sources

What references and data sources were used in completing this form?

Contact: Dr. Rong Murphy, phone: 479-575-2542, fax 479-575-2846, email: rymurph@uark.edu

4.0 Food Preservation: Drying, dehydration

4.1 If commercial, state manufacturer and specification or reference number:

Various commercial systems for drying and dehydration of food products are available (freeze-drying; air drying). Commercial systems are designed for the specific application of the food.

4.2 Current TRL (Refer to Appendix A):

The drying technology is proven for ground-based use (TRL 9). Prepackaged food products would be manufactured using existing commercial systems. Both atmospheric drying and freeze-drying have potential application for transit food system.

Atmospheric drying for a Mars based use would have to be developed. TRL 3.

Based on current crop selection, freeze-drying is not seen to provide any significant quality advantages over atmospheric drying.

4.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle (earth based technology only)

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

4.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Drying of food products for preservation is a proven technology and has been used by civilizations for thousands of years. The most effective method of drying or moisture removal would need to be identified for an Evolved Mars Base. Existing commercial systems would be acceptable to prepare food items for the transit vehicle and lander.

While current systems in Earth's atmosphere utilize the application of heat to evaporate moisture from foodstuffs, the technology may be modified (and possible made more efficient) if the drying chamber utilized a vacuum (i.e. no atmosphere; venting to a vacuum). Taking advantage of environmental conditions on Mars to facilitate the drying process could be advantageous.

The drying technology does not have unique requirements nor do such requirements exist for the technology to be successful.

4.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Microbial growth may be a hazard if drying is conducted between 40F and 140F for too long of a period. This may result in food pathogen growth if they are present, or food spoilage if nonpathogens are present.

Drying temperatures are generally in the range of 130F to 180F. Higher temperatures may be employed as long as it is proven for the specific food being dried. Too high of a temperature may result in case hardening, entrapment of moisture, spoilage due to microbial growth and nutritional loss.

Features could be incorporated into the system that defines the thickness of food to be dried, and then appropriate controls for time and temperature utilized. Measurement of residual moisture in the food could be monitored by sensors so that the system could be automated.

4.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Drying	Dependent upon crops grown; 1-5 years	Ambient or lower	75 RH or lower (if packaged)	Doesn't matter	Various types are acceptable

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

No

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

With dried food, there is a wide flexibility in acceptable packaging.

Note that these types of foods could be consumed as dried or consumed after rehydration.

4.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food (atmospheric drying)	5-7	6-8	5-7	5-7	5-7
Processed Food: (Freeze-drying)	7-8	7-8	6-8	5-7	3-5

Note: Results are very product specific.

4.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life
Drying	No gravity dependence	No effect on functionality or shelf life. May be able to utilize the atmospheric conditions (vacuum) to accelerate the drying process (e.g., vacuum in freeze-drying)

4.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)	3-4 kg	0.125 cubic meters	24 kW hours per batch; 1kW	None; however water liberated which could be recovered	0.5 hour/batch
Ground-based (TRL 4)	Not applicable				

Can the equipment be automated? To what degree?

Drying equipment should be able to be fully automated. It would require labor to add the food stuff to the equipment and remove it.

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

No optimal texture. Food products could be sliced, diced or shredded for ease in drying. Liquids could be dried down to "leathers".

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

Based on currently available bench-top unit.

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

The drying technology is proven and utilized today to manufacture prepackaged food items. This technology could be used to prepare foods required for transit, lander and initial Mars Base applications.

The work that needs to be done involves developing a scale model system for use in an Evolved Mars Base, and then identifying the appropriate processing parameters for the specific food items (e.g., shape and size of food items, drying temperatures, drying times, final moisture requirements, package size and type)

Evaporative water management from this process is a technical issue.

4.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Material/ Technology	Describe equipment clean-up	Water usage (liters per cleaning)	Chemicals used for processing	CM-h per clean-up
Drying	Periodic wipe down of equipment to remove food fragments	None	None	Minimal

4.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/ Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Drying	Five plus years	Heating element; motor; fan	Usage dependent; potential annual replacement of heat elements; valves, sensors

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Lack of preventive maintenance.

4.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Drying	Moisture recovery	Heat added to environment; moisture added to environment; odors to environment	Air/water

4.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Drying	Excellent	Low risk

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Drying	Temperature/humidity monitor	Water activity measure	Charting of temperature/humidity

4.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Drying			Improved drying methods such as microwave drying or radio-frequency drying could potentially improve this technology.	Determine if drying utilizing the vacuum in space could improve the efficiency of the system.

4.15 Data Sources

What references and data sources were used in completing this form?

Self knowledge

5.0 Food Preservation: Freeze dehydration

5.1 If commercial, state manufacturer and specification or reference number:

Oregon Freeze Dry, Albany OR; Hanover Foods, Lancaster, PA; CVC, CA; Dry Blenders: Alpine Aire, Backpackers

5.2 Current TRL (Refer to Appendix A): 8-9 (group packaging)

5.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

5.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Prepackaged components/meals, extended (5-20 years) shelf life, safe, highly acceptable, nutritionally stable, mature technology, wide range of products

5.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Microbial controls, browning reactions (decrease of flavor and rehydration), equipment vacuum chambers, refrigeration (gas lines), heat platens (oil lines)

5.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Freeze dry	3-20 years 6 mo-2yrs	70-80°F 100°F	0%	Atmospheric	Vacuum pkg, foil laminate

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

Product is highly susceptible to O2 and h2o degradation; do not recommend less permeable material, possible nanotechnology film.

5.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food	7-8	7-8	8	7-8	6-7

5.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment? NA

5.9 Processing Equipment Specifications - no information provided

5.10 Equipment Clean-up - no information provided

5.11 Equipment Lifetime - no information provided

5.12 System Integration - no information provided

5.13 Reliability, Monitoring and Control - no information provided

5.14 Technology Advances - no information provided

6.0 Food Preservation: Osmotic Drying

6.1 If commercial, state manufacturer and specification or reference number: Cherry Central Travers City, MI; Oregon Freeze Dry, Albany, OR; Tree Top (fruit); Graceland; Byron Foods, Australia

6.2 Current TRL (Refer to Appendix A): 4 or 5, 6 for fruits

6.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

6.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Osmotic drying: Air drying then infused with salts and sugars to moisture of @ 15% and Aw of < 0.86. Performance enhancing ingredients can be infused i.e. Ca, Folic acid, etc. Products have good shelf stability and compressibility

6.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Osmotic drying: Hazard in production, microbial control, dehydration equipment, vacuum pumps, heater coils

6.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Osmotic dry	3 year fruits; Other ingredients unknown	80 °F	0 % (foil pkg)	Atmospheric	Vacuum/N2 in foil laminate

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

Unknown shelf life with materials with higher permeability, possible EVOH

6.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food	7-8	7-8	7-8	7-8	7-8

6.8 Gravity Dependence - NA

6.9 Processing Equipment Specifications - no information provided

6.10 Equipment Clean-up - no information provided

6.11 Equipment Lifetime - no information provided

6.12 System Integration - no information provided

6.13 Reliability, Monitoring and Control - no information provided

6.14 Technology Advances - no information provided

6.15 Data Sources - no information provided

7.0 Food Preservation: Food Irradiation

7.1 If commercial, state manufacturer and specification or reference number: Food Tech Services/Nation's Pride, Mulberry Florida, Surebeam (Titan Corp), Iowa; IBA, Food Safety Division, (international); MDS Nordion, Kanata, ON, Canada, Steris, Isomedix Services, Mentor, OH; Natick Soldier Systems Center for high dose.

7.2 Current TRL (Refer to Appendix A): 7 for freshies, 9 for high dose products

7.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

7.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Prepackaged components/meals, extended (2-5) shelf life, safe, highly acceptable, nutritionally stable, mature technology, wide range of products. Fresh foods, extended shelf life, enhanced microbial safety.

7.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Irradiation processing may not be feasible for sometime due to weight of shielding needed and requirements for either isotope source or cooling systems for electrical or x-ray irradiation.

7.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Irradiation Low dose High dose	2 to 5 x 3-5 yrs	40F/ambient ambient	70 % 0%	Atms Atms	Polys Foil laminates

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Generally less shelf life at ambient-texture loss

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

Packaging material can changes for each item some MAP may extend shelf life further for freshies. For high dose products need hermetic packaging, foil laminates, possible nanofilms for future.

7.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food	8	8-9	8-9	7-8	7-8

7.8 Gravity Dependence - NA

7.9 Processing Equipment Specifications - no information provided

7.10 Equipment Clean-up - no information provided

7.11 Equipment Lifetime - no information provided

7.12 System Integration - no information provided

7.13 Reliability, Monitoring and Control - no information provided

7.14 Technology Advances - no information provided

7.15 Data Sources - no information provided

8.0 Food Preservation: Ohmic Heating

8.1 If commercial, state manufacturer and specification or reference number:

Manufacturers include APV, Raztek, Capenhurst.

8.2 Current TRL (Refer to Appendix A): 2

Ohmic heating has been developed for commercial applications, but will need additional research to be ready for space missions. In particular, systems need to be developed and redesigned for mission applications.

8.3 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

8.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Mars Surface Habitat Lander: Approximately 600 day stay on Mars per mission. A plant chamber would be available and would be responsible for growing more than just garden crops, and grown food would be the primary diet. Top-Level AFT Requirements: <u>Prepackaged food Items with a shelf life of 3 – 5 years that are safe, acceptable and provide the correct nutrition. Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops</u>.

The use of ohmic heating technology will assist the missions on three levels; in improving prepackaged food, being amenable to miniaturized for in-transit processing, and in on-site processing on the Mars/lunar surface. Ohmic, or Joule heating involves passage of alternating (or other waveform) electrical currents through food to heat it by internal energy generation.

Prepackaged food. First, since the quality and shelf-life of prepackaged food needs to be significantly superior to that of current thermally processed product. Ohmic heating systems have the unique advantage that a product containing liquid, solid, or solid-liquid mixtures can, with proper formulation, be heated rapidly with a <u>uniform thermal profile</u>. This ensures significant quality retention in comparison to conventional thermal processing treatments, where heat transfer to the interior dictates process time, resulting in significant quality loss. Ohmic heating has been found to result in products that have significantly improved quality retention (e.g. vegetables retain "crunchy" texture while being sterilized). It will also eliminate bacterial spores. Ohmic heating also has the advantage over microwaves, of a more uniform and easily predictable electric field distribution; thus the most minimally processed locations may be identified with greater confidence than microwave or radiofrequency heating.

In-transit heating. Ohmic heating is lightweight, and requires only an electrical power supply, and a food system that can be accommodated between electrodes. Space requirements are therefore minimal in comparison to most other heating technologies (it has been used for vending and dispensing applications). It is also suited to the available energy sources (electricity) in transit, which can be turned on or off at will. This technology can not only be used for simple heating of foods for consumption, but may also be useful in sterilizing any excess plant food harvest which cannot be consumed immediately, but may need storage prior to future consumption. It may be possible to create products (e.g. tomato sauce, vegetable purees, which are sterilized on-board and held for future consumption). This approach may also assist in menu variety over long-duration missions. A further use for in-transit ohmic heating would be in sterilization of waste product streams.

Heating at Mars/Lunar surface. Ohmic heating may be well suited for a Mars surface processing device, due to its simplicity, operation on electricity obtainable from solar cells, and the other advantages listed above. Since excess food production on Mars may potentially stored under frozen conditions, ohmic heating may be used as a thawing device for prefrozen products.

In order for ohmic heating to be successful, the food should possess at least a slight electrical conductivity. For example, most municipal water supplies may be heated with suitably designed ohmic heaters, however, fats and oils do not conduct electricity, thus ohmic heating cannot be used specifically for this purpose.

8.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Overheating of product without proper controls. This can be mitigated by use of suitable sensors; in particular current transducers which could easily detect overheating and take corrective action

Electrolytic production of hydrogen and oxygen. This is of serious concern at low frequencies, but can be mitigated or eliminated at higher frequencies. Further research is needed to optimize this parameter.

Migration of electrode materials into product. This may be mitigated by waveform and frequency control; and by suitable selection of electrode materials to ensure that any migration of metals is either within prespecified limits, or by selection of electrode materials which may provide benefits to humans in small doses. Research is needed in this area.

8.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

Do not have specific data. However, commercially sterile products can be produced, thus the shelf-life is in years at ambient temperature conditions. Research is needed on this topic

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Yes, it is expected to change with temperature, but specific data are not available.

8.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

We do not have specific data on this point, but our (and industrial experience) suggests that products are of significantly higher quality than conventionally processed food. This is a research need.

8.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life
Ohmic heating	No gravity dependence. Does not depend on natural convection as a heat transfer mechanism.	Gravitational changes are not expected to have an effect; however, the role of environmental conditions is less clear.

8.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

Data are not currently available since the systems will have to be developed for these uses; however, the energy efficiency is close to 100% since (excepting for heat losses) all energy is dissipated within the food. Crewtime can be reduced based on the wattage used.

Can the equipment be automated? To what degree?

Ohmic equipment can be completely automated.

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Not known

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

Systems can be designed for a specific crewtime.

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

For each application listed under section 10.4 above, a 2-3 year project to design, develop proof-of-concept and refine to optimization.

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

The principal restriction is the prior lack of knowledge regarding this technology. The issues are the development of heaters for specific tasks, the processing of product and testing of shelf-life and desired attributes, the optimization of cost, time and space consideration, as well as system integration.

8.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

If mechanical means of cleanup are included, the chemical requirements may be the same as that associated with normal process equipment.

8.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

These are unknown at this time. Research is needed. However, except for moving components, thus lifetimes may be several years.

8.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Ohmic heating	Sterilization of waste streams or of solid waste	Processing of excess production	Thawing of frozen product which could be stored at low-temperature conditions of the Martian surface

8.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Ohmic heating	With proper protocols and monitoring, this should be a highly reliable technology	

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature	Yes	Feedback (PID)	
Current	Yes	Feedback (PID)	

8.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Ohmic heating	Yes	Radiofrequency heating	Research projects are under way to understand electrolytic issues and to improve the rate of cooling following rapid ohmic heating to further improve product quality	

9.0 Food Preservation: Ohmic Heating/Radio-Frequency Processing for Mars-Based Mission

9.1 If commercial, state manufacturer and specification or reference number:

Manufacturers include APV, Raztek, Capenhurst; Strayfield

9.2 Current TRL (Refer to Appendix A): 2

Ohmic heating has been developed for commercial applications, but will need additional research to be ready for space missions. In particular, systems need to be developed and redesigned for mission applications.

9.3 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

9.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Mars Surface Habitat Lander: Approximately 600 day stay on Mars per mission. A plant chamber would be available and would be responsible for growing more than just garden crops, and grown food would be the primary diet. Top-Level AFT Requirements: <u>Prepackaged food Items with a shelf life of 3 – 5 years that are safe, acceptable and provide the correct nutrition. Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops</u>.

The use of ohmic heating technology will assist the missions on three levels; in improving prepackaged food, being amenable to miniaturized for in-transit processing, and in on-site processing on the Mars/lunar surface. Ohmic, or Joule heating involves passage of alternating (or other waveform) electrical currents through food to heat it by internal energy generation.

The use of radio frequency heating technology involves two components: the oscillation of the water molecule and the movement of ions within the foods.

Prepackaged food. Ohmic heating systems have the unique advantage that a product containing liquid, solid, or solid-liquid mixtures can, with proper formulation, be heated rapidly with a <u>uniform thermal profile</u>. This ensures significant quality retention in comparison to conventional thermal processing treatments, where heat transfer to the interior dictates process time, resulting in significant quality loss. Ohmic heating has been found to result in products that have significantly improved quality retention (e.g. vegetables retain “crunchy” texture while being sterilized). It will also eliminate bacterial spores. Ohmic heating also has the advantage over microwaves, of a more uniform and easily predictable electric field distribution; thus the most minimally processed locations may be identified with greater confidence than microwave or radiofrequency heating. Radio frequency heating may have significant advantages for specific products (eggs, mac & cheese, broccoli)

In-transit heating. Ohmic heating is lightweight, and requires only an electrical power supply, and a food system that can be accommodated between electrodes. Space requirements are therefore minimal in comparison to most other heating technologies (it has been used for vending and dispensing applications). It is also suited to the available energy sources (electricity) in transit, which can be turned on or off at will. This technology can not only be used for simple heating of foods for consumption, but may also be useful in sterilizing any excess plant food harvest which cannot be consumed immediately, but may need storage prior to future consumption. It may be possible to create products (e.g. tomato sauce, vegetable purees, which are sterilized on-board and held for future consumption). This approach may also assist in menu variety over long-duration missions. A further use for in-transit ohmic heating would be in sterilization of waste product streams.

Heating at Mars/Lunar surface. Ohmic heating may be well suited for a Mars surface processing device, due to its simplicity, operation on electricity obtainable from solar cells, and the other advantages listed above. Since excess food production on Mars may potentially stored under frozen conditions, ohmic heating may be used as a thawing device for prefrozen products.

In order for ohmic heating to be successful, the food should possess at least a slight electrical conductivity. For example, most municipal water supplies may be heated with suitably designed ohmic heaters, however, fats and oils do not conduct electricity, thus ohmic heating cannot be used specifically for fats or oils.

9.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Overheating of product without proper controls. This can be mitigated by use of suitable sensors; in particular current transducers which could easily detect overheating and take corrective action

Electrolytic production of hydrogen and oxygen. This is of serious concern at low frequencies, but can be mitigated or eliminated at higher frequencies. Further research is needed to optimize this parameter.

Migration of electrode materials into product. This may be mitigated by waveform and frequency control; and by suitable selection of electrode materials to ensure that any migration of metals is either within prespecified limits, or by selection of electrode materials which may provide benefits to humans in small doses. Research is needed in this area.

Operational hazards for equipment: Potential shock hazard; potential EMI interference; pressurized chamber needed for commercialization sterilization

9.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

Do not have specific data. However, commercially sterile products can be produced, thus the shelf-life is in years at ambient temperature conditions. Research is needed on this topic

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Radio frequency	3 – 5 years; similar to retorted items or better	40F – 80F	Not an issue for product; potential issue for packaging material	Ambient	Poly trays; pouches; cans

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Yes, it is expected to decrease with increasing temperature, but specific data are not available.

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

Wet pack shelf stable food requires hermetic seal; poly tray has slight O_2 transference, ideal packaging foil/can.

9.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

We do not have specific data on this point, but our (and industrial experience) suggests that products are of significantly higher quality than conventionally processed food. This is a research need.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food	8-9??	8-9??	7-8 ???	7-9 ??	7-8

9.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life
Ohmic heating	No gravity dependence. Does not depend on natural convection as a heat transfer mechanism.	Gravitational changes are not expected to have an effect; however, the role of environmental conditions is less clear.

9.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

Data are not currently available since the systems will have to be developed for these uses; however, the energy efficiency is close to 100% since (excepting for heat losses) all energy is dissipated within the food. Crewtime can be reduced based on the wattage used.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2) - Ohmic Heating	8-10 kg	0.5	1.4 kWH for a 12 liter batch; 16.8 kW /batch	none required	4 hours/batch for processing; 5 minutes for reheating already processed product
Theoretical (TRL 2) - Radio frequency processing	50 kg	1 – 1.5 (to produce a 2.5 kg batch)	2.0 kWH; 8kW	3 liters DI water per batch; can be re-used	4 hours/batch for processing
Ground-based (TRL 4)					

Can the equipment be automated? To what degree?

Ohmic equipment and radio frequency can be completely automated.

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

No, but certain conductivity range of product is required for a given piece of equipment.

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

Based on current prototype equipment and best guess.

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
Ohmic heating/radio frequency	10 – 15 MYE	900K-1500K

For each application listed under 11.4 above, a 2-3 year project to design, develop proof-of-concept and refine to optimization

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

The principal restriction is the prior lack of knowledge regarding this technology. The issues are the development of heaters for specific tasks, the processing of product and testing of shelf-life and desired attributes, the optimization of cost, time and space consideration, as well as system integration. Downsizing of the unit for radio frequency is an unresolved issue. In-package ohmic heating would require development of packages with electrodes attached/embedded. For bulk ohmic heating, development of a packaging system would be necessary. For ohmic heating, the composition of the electrodes is an open technical issue. Graphite might be a useful material for a single-use electrode system. Radio frequency technology is primarily limited to non-metallic packaging (like microwave).

9.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

If mechanical means of cleanup are included, the chemical requirements may be the same as that associated with normal process equipment. Clean-up requirements would be the same as for retorting.

9.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

These are unknown at this time. Research is needed. However, except for moving components, thus lifetimes may be several years.

Material/ Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Ohmic heating/radio frequency heating	Depends upon operating hours, however at least 5000 hours of operation would be expected.	Life of the electrodes is the limiting factor for bulk Ohmic heating (earth based use).	

9.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Ohmic heating/radio frequency heating	Potential use for sterilization of waste streams or solid waste; potential use as a reheating/thawing device for pre-packaged food; potential use to cook with either of these technologies	Potential radio frequency interference; potential high currents/heat liberation to environment; potential biological concerns for radio frequency exposure	Air; control systems

9.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Ohmic heating; radio frequency heating	Ohmic heating has potentially high reliability for producing commercial sterile products; radio frequency heating still needs further verification of heating uniformity and ability to consistently achieve commercial sterility during processing	Potential food safety issues if processing is inadequate; of particular concern in Ohmic heating are foods which contain large particulate matter with lower conductivity than the bulk fluid in the product.

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature, current, voltage; offline measurement of electrical conductivity of food prior to processing; for radio frequency heating monitor of electromagnetic field is needed.	Yes	Yes; feedback control (proportional integral derivative); feed forward control might be feasible/desirable	

9.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Ohmic heating/radio frequency heating	Microwaving	Package development for ohmic heating	Research projects are under way to understand electrolytic issues and to improve the rate of cooling following rapid ohmic heating to further improve product quality Active research programs exist in both these technologies	

10.0 Food Preservation: High Hydrostatic Pressure Processing

10.1 If commercial, state manufacturer and specification or reference number:

Avure Technologies (a subsidiary of Flow International Corporation, Kent, WA); Mitsubishi,Japan; Kobeco, Japan; Uhde, Germany; APS, France; EPSI, Belgium; Stanstedt, UK; Polish Academy of Sciences

10.2 Current TRL (Refer to Appendix A):

High-acid shelf stable TRL 8 (used on STS-65 by Dr. Chiaki Mukai, Japan- 1994)

Low-acid shelf stable TRL 5

10.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

10.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

High hydrostatic pressure (HHP) food processing can be used to process prepackaged foods without significantly degrading nutritional and sensory qualities. HHP treatment avoids high thermal exposure and avoids the use of chemical additives. The use of high pressure to increase food safety and shelf-life has been studied for over 100 years. Current advances in engineering have enabled the development of cost-effective equipment for HHP food processing. Shelf-stable high-acids foods have already been demonstrated. Shelf-stable low acid foods are currently under development. The low acid product process combines high pressure with elevated temperatures to achieve sterility. These low acid foods however will require FDA approval prior to commercialization due to the LACF regulations.

10.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

HHP will most likely be used as an earth based food-processing technology to supply space travelers with high quality, long shelf-life foods. The risks associated with HHP equipment are typically related to the use of high-pressure mechanical equipment. However, since the compressibility of water is relatively low, the amount of compression energy stored in a HHP food processor vessel is less than that expected from a high-temperature steam retort used for sterilization (i.e. Canning). The temperatures associated with HHP are lower than that associated with thermal processing. No hazardous chemicals are used and no dangerous pollutants are released.

10.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

HHP processed foods can exhibit shelf-life ranging from extended refrigerated storage of several weeks to shelf stable products lasting several years. The specific life can be controlled by adjusting the time, temperature, and pressure of treatment. HPP at chilled or room temperatures produce a fresh like product with microbiological effects equivalent to pasteurization but with greater sensory and nutritional quality. For the most part, enzymes are not inactivated.

HHP processing at higher temperatures (typically starting at an initial temperature of 80C or greater), and sometimes with pressure pulsing, produces a sterilization effect, as well as enzyme inactivation. The packaging material requirements are understood. Packaging must be able to allow physical compression of the product. Most food-grade flexible pouches work well under HHP. Rigid glass or metal containers are not compatible. Packaging for extended shelf-life needs to incorporate appropriate barrier and light properties in order to minimize chemical changes that will eventually degrade quality. Since HHP processed foods can be chemically degraded by prolonged storage under high temperatures, the lower the storage temperature, the longer the product will retain a condition of high quality.

10.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food -(acidified/high acid pasteurized)	7-9	7-9	7-9	7-9	7-9
Processed Food - (shelf stable products/mostly low acid)	7-8	7-8	6-8	7-8	6-9

Processed Food (acidified/high acid pasteurized):

HHP inactivates microorganisms by disrupting large macromolecules responsible for cellular function. Small molecules responsible for taste, color, nutrition, odor, are much less impacted. Thus, these qualities remain after HHP processing. The texture of many foods is also not impacted by HHP. However, HHP works best for high water content foods like juices, sauces, stews, soups, meats, etc. Overall quality may still be impacted over time by remaining enzyme activity. High-air content foods such as a whole apple, or cut cantaloupe tend to show softening after HHP processing. HHP does not appear to work on dry products like cereals

Processed Food (shelf stable products/mostly low acid):

HPP under increased pressure and at higher temperatures will lead to increased microbial inactivation. This can lead to the destruction of spores, which will enable shelf-stable low acid product production. For these products, while the characteristics will not be “fresh-like”, the quality will certainly be higher than conventionally retorted foods. Some preliminary quality studies of HHP sterilized foods have suggested that their quality can approach that of refrigerated lightly cooked products.

10.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

HPP processing is not inherently gravity dependent. However, the weight of the processing equipment will be a factor when consideration if attempting to fly this technology. Lighter composite based pressure vessel technology can be built, but this will involve a significant R&D effort.

10.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)	500 kg	Processing volume 2 liters; footprint of equipment 2.0 cubic meters	20 kW maximum for short time; 2 KW hours/batch	1 liter	3.0 hours/3 liter batch
Ground-based (TRL 4)		Not applicable for ground-based.			

HHP processing involves less energy usage when compared to conventional thermal pasteurization or sterilization processing. High pressure processing requires high power levels for short periods of time, but overall lower total energy consumption. HHP equipment is substantially heavier and bulkier than conventional food processing equipment. HPP equipment can recycle much of the process water and is not a high user of water. HPP equipment relies on electricity as its primary source of energy.

Can the equipment be automated? To what degree?

Yes, productivity and cost driven.

This equipment is not recommended for flight use due to weight.

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

See 12.7

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

Based on current production systems.

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

High acid product development needs to be performed to optimize product formulation for NASA use.

Low acid products will require substantial food safety validation and process development. This is currently underway within industry, government and academic locations.

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

HHP processing clearly impacts many sectors within food processing and outside. Although the science of the effects of high pressure on biological systems has been studied for over 100 years, significant research is still on going. The ability to destroy microorganisms with the minimal use of temperature has applications for medical, biotech products and many other areas. Non-microbiological applications of HHP biomaterial processing can range from improved food textures to protein modification, virus inactivation to vaccine production. The main technical issue for low acid shelf stable products is the microbiological modeling of spore inactivation in order to achieve regulatory approval.

10.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Equipment can be cleaned using conventional food industry methods. Since processing can take place with sealed consumer ready packages, equipment exposure to foods contact is minimal. As indicated earlier, the weight of the HHP equipment would limit technology for ground-base use.

10.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Equipment lifetime should not be an issue for ground-based use of this technology to supply NASA with food products.

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Equipment wear and tear along with improper or the lack of preventative maintenance will damage or degrade the technology.

10.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

This technology is not recommended for in-flight use.

10.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

HHP is already a commercial technology and has high reliability. When utilized under an appropriate HACCP plan, the technology will produce a safe and stable product.

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

HHP processing requires the monitoring of time, temperature, and pressure parameters. In addition, the process should be integrated into a full HACCP plan for food safety.

10.14 Technology Advances

HHP is different from other food processing technologies. The mechanism of inactivation is different from thermal, or other nontraditional methods such as pulse electric field and ionizing irradiation.

HHP processing is undergoing extensive industry developments. The US Army Dual Use Science and Technology (DUST) consortium is working on the issues related to shelf-stable low acid food commercialization. A number of food companies are also working on HHP sterilization R&D.

Additional research into the inactivation kinetics and inactivation mechanisms of bacteria and bacteria spores will benefit the understanding of this technology and enable regulatory rule making. Research into product formulation to optimize for HHP will be important. Additional developments into equipment integration into food production lines will also be important.

10.15 Data Sources

What references and data sources were used in completing this form?

Many hundreds of scientific papers have been published on various aspects of high pressure food processing. Some selected references are linked below:

http://vm.cfsan.fda.gov/~comm/ift-hpp.html (FDA Kinetics of Microbial Inactivation for Alternative Food Processing Technologies -High Pressure Processing, U. S. Food and Drug Administration, Center for Food Safety and Applied Nutrition, June 2, 2000)

http://avure.com/science_hpp_review.htm (Avure Technologies web site)

11.0 Food Preservation: Refrigeration

11.1 If commercial, state manufacturer and specification or reference number: Maytag Climate Zone Technology Maytag Corporation, 403 West Fourth Street North, Newton, IA 50208

11.2 Current TRL (Refer to Appendix A): 6

11.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

11.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops. Some food preservation technologies may be used to preserve the processed ingredients.

Extend shelf-life via temperature control – reduce respiration of salad crops, slow microbial spoilage. Useful for fresh and processed products, including leftovers during all three phases of this mission.

Requirements: energy; temperature control for various classes of foods; cleanable; resistant to odor problems; storage containers

The objective for the use of Maytag ClimateZone™ Technology is as a post-harvest procedure / technology to aid in providing acceptable, safe and nutritious salad crops. The Maytag ClimateZone™ Technology extends the storage life of produce by accurately setting and maintaining the ideal temperature for produce at 34F with minimal temperature variation to slow ethylene production and ripening which lead to produce spoilage. The Maytag ClimateZone™ Technology prevents air from drying produce by pumping the cold air through multiple chambers surrounding the storage drawers rather than directly on the produce. Automatically controlling humidity with use of a porous material that allows excess moisture to exit, maintaining optimal humidity levels between 90 – 100%.

11.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Hazards If loss of refrigeration: Microbial spoilage – hazard if pathogens present; odor; spoilage –waste systems.

Proper use of antimicrobial surface wash; if damaged – possible refrigerant loss to environment

11.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Refrigeration	Shelf life salad crops (days not years unless dried or frozen – see separate technology worksheets)	Storage temperature 38F or lower ideal, higher if perishable foods	Storage relative humidity varies on crop or food stored	Storage pressure atm unless hypobaric pressures are used	Packaging: semipermeable or high barrier packaging depending on product. Should be cleanable

Testing conducted on the Maytag ClimateZone™ Technology by Jeffrey K. Brecht, Ph.D., Postharvest Plan Physiologist in the Horticultural Sciences Department at the University of Florida in 1999 compared storage of various fruits and vegetables at 34, 37 and 40 degrees F. The tests were designed to simulate storage of produce in a home refrigerator. Key differences observed included:

Overall appearance and/or sensory quality was better maintained at 34 degrees F. than 37 degrees F. for apple (whole and fresh-cut), peach (whole and fresh-cut), broccoli (whole and fresh-cut), asparagus, strawberry, Iceberg lettuce, and Romaine lettuce, translating into predicted increases in storage life of from 2 to 8 days.

Green color as measured by the chromameter was better maintained at 34F than 40F for apples and broccoli, plus Iceberg and Romaine lettuce, but the color did not differ between 34 and 37F.

Soluble solids levels were maintained better at 34F than at either 37 or 40F for apples, peaches and grapes.

Vitamin C content was higher in peaches at 34F compared to 40F early in storage and, in kiwis and strawberries, vitamin C was higher at 34 and 37F than at 40F at the end of storage.
A complete report of the testing methodology and results is available and was submitted to NASA in 2000.

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Depending on ambient temperature, the storage life of fresh harvest crops could be less than one day.

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

Yes for some products

11.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food	9	9	9	9	8

Processed Food - not processed but stored in carefully controlled temperature & humidity conditions for the salad crops will increase storage life from 2 to 8 days with overall appearance and sensory quality at very acceptable consumption levels.

11.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

The Maytag ClimateZone ™ Technology has not been tested in fractional gravity or weightlessness to determine its effect.

11.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

No information provided

Can the equipment be automated? To what degree?

The Maytag ClimateZone ™ Technology is already automated. The user simply presses the button corresponding to the type of food to be stored (choice of Produce, Citrus or Meats)

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Yes, due to temperature and relative humidity and time of storage. The Maytag ClimateZone ™ Technology has been specifically designed for citrus and tropical fruits, other produce and for fresh meats and seafood.

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

Energy; Space in transit vehicle?

11.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Cleanup is only necessary if food is stored until it spoils in the compartment. The material is polycarbonate and can be cleaned with water and chlorine bleach or peroxide.

11.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

The average life of a household refrigerator is over 10 years.

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Compressor/power failure

11.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Demands power. If failure occurs or if crew let products stay too long spoilage occurs –waste, air odor

11.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

The Maytag ClimateZone ™ Technology refrigerator has been on the market in the United States and Canada since 1999. It has proven to be reliable.

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature; refrigerant pressure	Yes	Temperature control	None

11.14 Technology Advances

This technology may need to be “downsized” for extraterrestial use.

11.15 Data Sources

References: postharvest and processing/preservation

12.0 Food Preservation: Freezing

12.1 If commercial, state manufacturer and specification or reference number: Maytag corporate partner; other companies.

12.2 Current TRL (Refer to Appendix A): 4

12.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle (Small unit for special occasions.

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

12.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

<u>Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops. Some food preservation technologies may be used to preserve the processed ingredients.</u>

Preserves food - high quality, except textural changes with slow freezing. Ties up water in ice crystals and reduces growth and chemical reactions (except oxidation).

12.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Hazards- coolant/compressor/power failure. Redundant systems, monitoring with alarms. If power failure, products will thaw, spoilage could occur – odor and solid waste.

12.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Freezing	3 years	-20 C			High barrier film or container

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Yes. If thawed, a couple of hours unless refrigerated.

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

The same

12.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	9	9	9	9	9
Processed Food					

12.8 Gravity Dependence – no information provided

12.9 Processing Equipment Specifications

Can the equipment be automated? To what degree?

Yes but not needed for these missions.

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Yes, fast freezing is best to maintain good to acceptable texture of vegetables and food products

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)? no information provided

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

Power

12.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Material/ Technology	Describe equipment clean-up	Water usage (liters per cleaning)	Chemicals used for processing	CM-h per clean-up
Existing	Thaw, wipe sanitizer	Minimal	Peroxide or other approved sanitizer	Size dependent

12.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/ Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Existing	10 plus years	?	?

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Power loss, compressor failure, high temperatures.

12.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Freezer	Better food	Power	If failure occurs, air, solid waste

12.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Freezing	Good	See Maytag

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature; pressure	Yes	Yes	Recording only?

12.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Freezing	Yes	Blanching some fresh vegetables before freezing. Thawing system		

12.15 Data Sources

What references and data sources were used in completing this form?

Food Processing and preservation texts. Experience.

13.0 Food Preservation: Controlled water activity – a Hurdle technology for use with high barrier film

13.1 If commercial, state manufacturer and specification or reference number:

Kraft Foods "It's Pasta Anytime" product acquired from Borden

13.2 Current TRL (Refer to Appendix A): 5

13.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☐ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

13.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Water activity is controlled to retard microbiological growth and enzymatic activity. Biochemical activity is slowed. Product is ambient temperature shelf stable and of reasonable quality for consumers. Can be consumed at ambient or elevated temperatures.

13.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

If package integrity is breached, microbiological contamination can occur with potential for pathogenic microbiological growth.

13.6 Material Physical Factors

For each technology, list the known physical properties of the packaging material.

Material/ Technology	Permeability to gas (including oxygen)	Light Transmissivity	Moisture Barrier specifications	Material mass per area	Packaging Type (flexible, semi-rigid, rigid)
Total barrier in flexible and/or flexible plus semi-rigid tray	Pouch or semi-rigid tray heat sealed	Should be zero Should be opaque	Product dependant		Flexible high-barrier pouch or semi-rigid aluminum tray with heat-seal flexible aluminum foil closure

Provide a qualitative evaluation of the following material properties. Where applicable, use a scale of 1-9 where 1 is very poor and 9 is excellent.

Material/ Technology	Specialized attributes	Biodegradability (# of years to breakdown)	Recyclability	Reusability (can this material be reused after the food has been consumed?)	Effect of physical properties upon acceptability of food
Aluminum foil lamination	Pouch is horizontal form/fill/seal; semi rigid tray is preformed tray deposit /fill/seal. All materials with interior heat sealant for fusion sealing	None	No	Tray can be reused if desired	Interior heat sealant can scalp flavor at ambient temperature after about four months with flavor scalping continuing through entire shelf life.

Material Chemical Composition

Material/Technology	Chemical composition	Describe any offgassing concerns
Aluminum foil lamination		None

Evaluate the Temperature limitations of the packaging material

Material/Technology	Microwavable (Y/N)	Freezable (Y/N)	Temperature Range (^{o}C)	Effect of temperature on packaging and food interaction
Flexible: polyester or nylon/ aluminum foil/linear low density polyethylene. Semi-rigid drawn aluminum foil with linear low density interior extrusion coating	No	Yes		As ambient temperature increases, so also does propensity for flavor scalping

13.7 Packaging Design

Technology	How does package design enhance food quality?	How has convenience affected the package design?
Flexible pouch	Retards entry of moisture that would adversely affect food contents	Flexible pouch can be manually torn open with appropriate notching. Semi-rigid tray may be opened by peeling the top flexible closure.

13.8 Based on the technology, evaluate the stability of the packaging material in terms of resistance to microorganisms, strength, stiffness, and formability. Where other units are not specified, use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Packaging Material	Material shelf life (years)	Describe materials resistance to microorganisms	Material strength	Material formability	Types of foods used for*
Flexible: polyester or nylon/aluminum foil/linear low-density polyethylene. Semi-rigid drawn aluminum foil with linear low density interior extrusion coating	Indefinite	Susceptible to impact, puncture, abrasion, to permit entry of microorganisms			Stabilized by control of water activity plus thermal pasteurization plus pH control; hurdle or combination technology. Can be used for starch dishes such as pasta, rice, noodles, some soft bakery goods, some cooked animal protein products.

13.9 Food Packaging Equipment, Packaging Material Information

Does the packaging material technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness?

Packaging Material	Describe material gravity dependence	Describe gravity effect on temperature range of material
Flexible: polyester or nylon/aluminum foil/linear low density polyethylene. Semi-rigid drawn aluminum foil with linear low density interior extrusion coating	Unknown	Unknown

What would prevent the current packaging equipment from being operated upside down in a terrestrial environment?

The processing and packaging would be conducted on Earth. Current commercial equipment would probably not function effectively inverted.

Equipment technology	Suitable for ground operations?	Suitable for planetary surface	Unique to one packaging technology? If not, list other technologies with same traits
Flexible pouch: horizontal form/fill/seal analogous to Bartelt. Semi rigid tray; preformed tray deposit/fill/seal similar to Ross Reiser	Both fillers positive displacement		

13.10 Packaging Equipment Specification – no information provided

For each food packaging technology, estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

The equipment appears satisfactory for ground-based food preservation. Highly questionable for extraterrestrial operation.

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

About 1.5 years to validate this processing/packaging technology for long-term ambient use.

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

Can this product be microbiologically safe? And is the product acceptable to target consumers?

13.11 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Material/ Technology	Describe Equipment Clean-up	Water usage (liters per cleaning)	Chemical usage	CM-h per clean-up
Controlled water activity	Equipment must be cleaned and sanitized after each use.			

13.12 Equipment Lifetime

Describe the expected lifetime of the food packaging equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Controlled water activity	10 years		

13.13 System Integration: Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Controlled water activity	Product quality should be better than thermally sterilized		

13.14 Reliability, Monitoring and Control: What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe packaging reliability	Evaluate packaging risk
Controlled water activity	Reliability not thoroughly tested. The few tests to date have indicated safely, but the data are not definitive.	

What sensor data and controls are necessary to insure the packaging equipment is functioning properly? What long term measurements are necessary to insure the functionality of the packaging material? What data processing is needed to relate the sensor data to the control data?

Technology	Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs	Test available to measure quality of packaging material?
Controlled water activity					Package integrity is absolutely mandatory.

13.15 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Controlled water activity	Yes	Japanese	Cooked rice	

14.0 Food Preservation: Fruit Straws

14.1 If commercial, state manufacturer and specification or reference number:

Working with East West Medical Research Institute to commercialize technology

14.2 Current TRL (Refer to Appendix A): 6

14.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

14.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Fruit straws are nutritious and can be easily fortified to meet the needs of astronauts. The straws themselves could be stored for up to 3 years if packaged under the correct conditions. They can be manufactured from up to 100% fruit.

The straws also offer the potential to reduce the amount of disposable straws used on Mars missions. The straws would be eaten after use.

14.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

No hazards identified.

14.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Fruit Straw	3 years	2C	30%		Metallized Mylar

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Yes, we anticipate a 1-year shelf life FOR A STRAW at room temperature

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

Depends on the packaging material used, but the shelf life would be reduced if the material was more permeable

14.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	7	7	7	7	7
Processed Food	8	6	6	6	8

14.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life
Straw	None once they are formed	No

14.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

There are two possible scenarios for using these straws in space. The straws could be manufactured on earth before the missions and/or they could be formed during the missions from crops grown in space. To manufacture them in space grinding, extrusion and dehydrating equipment would be required.

14.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Material/ Technology	Describe equipment clean-up	Water usage (liters per cleaning)	Chemicals used for processing	CM-h per clean-up
	Grinding, dehydrate, extrusion, wash down	2 L	Ascorbic acid	

14.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
	5 years		

14.12 System Integration – no information provided

14.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Dehydration	High	Low

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature	Yes		

14.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Grinding Dehydrating Extrusion	Yes	Yes	Yes	

15.0 Food Preservation: Fruit and Vegetable Wraps

15.1 If commercial, state manufacturer and specification or reference number:

Working with Aquafilm, LLC to commercialize technology

15.2 Current TRL (Refer to Appendix A): 6

15.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☐ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

15.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Fruit and vegetable wraps can help extend the shelf life of food products and enhance their nutritional value. The wraps themselves could be stored for up to 3 years if packaged under the correct conditions. The wraps are nutritious. They can be manufactured from up to 100% fruits and vegetables and can be easily fortified. The wraps can be used as alternatives to tortillas to ease consumption of foods during missions to space.

The wraps also offer the potential to reduce the amount of disposable packaging used on Mars missions and could be used, for example, to wrap astronaut suits. The wrap would later be eaten.

15.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

No hazards identified.

15.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Wrap + Pkg	3 years	2C	30%		Metallized Mylar
Wrap Alone	1 year	2C	30%		None

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Yes, we anticipate a 1-year shelf life FOR A PACKAGED WRAP at room temperature

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

Depends on the packaging material used, but the shelf life would be reduced if the material was more permeable.

15.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

	Nutrition	Flavor	Color	Odor	Texture
Raw Food	7	7	7	7	7
Processed Food	8	7	8	7	7

15.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life
Wraps	None once they are formed	No

15.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

There are two possible scenarios for using these wraps in space missions. The wraps could be manufactured on earth before the missions and/or they could be formed during the missions from crops grown in space. To manufacture them in space grinding and dehydrating equipment would be required. I do not know what the relative humidity is on Mars, but perhaps it's low humidity and high temperatures could be used for dehydration of fruits and vegetables on Mars. Novel dehydrators could be developed to take advantage of the ambient conditions on mars for food processing uses.

15.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Material/Technology	Describe equipment clean-up	Water usage (liters per cleaning)	Chemicals used for processing	CM-h per clean-up
Dehydrators	Very little	0.5 L	Ascorbic acid	

15.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Dehydrator	5 years		

15.12 System Integration – no information provided

15.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Dehydration	Highly	Low risk

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature	Yes		

15.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Dehydration	Yes			

Technology Assessments: Post-harvest Processing

1.0 Post-harvest Processing: Fermentor/Bioreactor

1.1 If commercial, state manufacturer and specification or reference number: Labconco

1.2 Current TRL (Refer to Appendix A): 4

1.3 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

1.4 Functions

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Used to convert starch to sugar for use as sweetener or as energy for fermentation products (yogurt, soy sauce, miso, alcoholic beverages).

1.5 Hazard Identification

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Microbiological, Fire (alcohol), Volatiles

1.6 Shelf Life

Based on the technology, evaluate or describe the stability of the processed crop. Please state the stability of the harvested crops when stored under optimum conditions. Those conditions should be stated in the table (4th column).

Technology	Harvested crop shelf life (years)	Describe steps taken to ensure no loss in crop functionality (temperature, relative humidity, etc.)	Describe steps taken to ensure that ingredients remain stable after post-harvest processing	Nutritional content of processed crop vs. original food state	Type of packaging needed to provide highest degree of food acceptability
Fermentor/ Bioreactor	Indefinite	Excessive heating	Temperature control and relative humidity	Probiotic effects	Moisture barrier

1.7 Gravity Dependence

Does the processing technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? In other words, what would prevent the current processing equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity will affect crop functionality or shelf life
Fermentor/Bioreactor	None	No

1.8 Processing Equipment Specifications

For each component in the post-harvest processing technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Emissions generated during processing	Crewtime (CM-h per use)
Theoretical (TRL 2)						
Ground-based (TRL 4)	30-40	0.3	1	10	Volatiles CO_2 (with yeast)	0.5

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Depends on product

Can the equipment be automated? Yes **To what degree?** 90-95%

Are the mass, volume, power, and crewtime numbers based on a currently existing system. Yes

If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to reach TRL=5	Labor costs to bring technology to TRL=5
Fermentor/ Bioreactor	1000	$0.1M

1.9 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Technology	Describe equipment clean-up	CM-h per clean-up	Water usage (liters per cleaning)	Chemicals used for processing
Fermentor/ Bioreactor	CIP	0.2	10L	None (enzyme)

1.10 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Fermentor/ Bioreactor	>10 years	Seals	minimal

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Radiation, excessive heat

1.11 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this processing technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Fermentor/ Bioreactor	CO_2	Volatiles Solids in cleaning	Air and water

1.12 Post-harvest Processing Operations

Technology	Suitable for ground operations?	Suitable for planetary surface (partial gravity)	Unique to one processing technology? If not, list other technologies with same traits
Fermentor/ Bioreactor	Yes	Yes	No (sugar conversion in extruder, STOW, or FVP)

1.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Fermentor/Bioreactor	High	Low

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature Refract. Sensor CO_2	Yes Yes Yes	Yes	Yes

1.14 Technology Advances – no information provided

1.15 Data Sources – no information provided

2.0 Post-harvest Processing: Breadmaker

2.1 If commercial, state manufacturer and specification or reference number: Breadman, Sanyo, Zojirushi, Bready, Wellbilt

2.2 Current TRL (Refer to Appendix A): 4

2.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

2.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Can be used for processing flours into bread as well as pasta kneading

2.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Volatiles and heat.

2.6 Food Shelf Life

Based on the technology, evaluate or describe the stability of the processed crop. Please state the stability of the harvested crops when stored under optimum conditions. Those conditions should be stated in the table (4th column).

Technology	Harvested crop shelf life (years)	Describe steps taken to ensure no loss in crop functionality (temperature, relative humidity, etc.)	Describe steps taken to ensure that ingredients remain stable after post-harvest processing	Nutritional content of processed crop vs. original food state	Type of packaging needed to provide highest degree of food acceptability
Breadmaker	.01-2	Relative humidity control, Temperature	Refrigeration/ Freezing		Moisture barrier

2.7 Gravity Dependence

Does the processing technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? In other words, what would prevent the current processing equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity will affect crop functionality or shelf life
Breadmaker	Unknown	No

2.8 Processing Equipment Specifications

For each component in the post-harvest processing technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Emissions generated during processing	Crewtime (CM-h per use)
Theoretical (TRL 2)						
Ground-based (TRL 4)	1	.25	1.2	None	Volatiles (ex. hexanal, acetaldehyde)	0.2

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Depends on desired properties of bread

Can the equipment be automated? Yes To what degree?

90%

Are the mass, volume, power, and crewtime numbers based on a currently existing system. Yes

If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to reach TRL=5	Labor costs to bring technology to TRL=5
Breadmaker	1000	$0.1M

2.9 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Technology	Describe equipment clean-up	CM-h per clean-up	Water usage (liters per cleaning)	Chemicals used for processing
Breadmaker	Vacuum	0.1	None (wipe)	None (yeast)

2.10 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Breadmaker	2 years	Bags for ingredient mixing (Bready), paddles, motors	Minimal

What relevant compounds and circumstances will degrade the performance of or damage the technology?

None

2.11 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this processing technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Breadmaker		Volatiles	Air

2.12 Post-harvest Processing Operations

Technology	Suitable for ground operations?	Suitable for planetary surface (partial gravity)	Unique to one processing technology? If not, list other technologies with same traits
Breadmaker	Yes	Yes	Extruder (flat bread)

2.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Breadmaker	High	Low

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature Farinograph	Yes No	Yes	Yes

2.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Breadmaker	Yes			Incorporation of farinograph

2.15 Data Sources

What references and data sources were used in completing this form? – no information provided

3.0 Post-harvest Processing: Extruder

3.1 If commercial, state manufacturer and specification or reference number: Brabender, Clextral

3.2 Current TRL (Refer to Appendix A): TRL 3

3.3 Mission(s) for which this form is being completed (check one or more of the following options):

- ☐ Mars Dual Lander Transit Vehicle
- ☒ Mars Dual Lander Surface Habitat
- ☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

3.4 Functions

What are the objectives in implementing the technology in accordance with the mission requirements for AFT? Please use the same wording as given in the mission requirements section (Section 2). The technology may satisfy more than one of the requirements for a particular mission in Section 2, in which case the researcher/technology developer should enumerate the satisfied requirements.

Extrusion would be used as a post-harvest technology to aid in providing acceptable, safe and nutritious processed food crops. It can also be regarded as a preservation technology as it can produce foods are shelf stable if packaged correctly due to their having low moisture level and microbial count.

Extrusion is a flexible, continuous, rapid, high automated, low gravity dependent technology for converting food ingredients into a wide variety of finished products. It works by forcing raw materials through a heated cylinder using an Archimedes screw thereby subjecting the food to high temperature, shear and pressure environment. Cooking is extremely rapid as it inputs both mechanical and thermal energy into the product.

Extrusion can create a wide variety of products. Industrially it is used to create expanded snack products, dry breads, pasta, confectionary, and vegetable protein meat analogs. As well as significantly reducing the size and mass of the extruder, it is also envisioned that the same apparatus could be redesigned to also perform a variety of additional tasks including milling grain, expelling oil from seeds as well as reducing the microbial content and moisture of waste materials.

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

General capabilities: mixing, heating (cooking), shearing, oil expression, pumping, texturizing, forming, (e.g., snacks, breakfast cereals, pasta, shapes)

3.5 Hazard Identification

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Extrusion is a low hazard technology. Hazards include high temperatures (60 – 250°C) and high pressures (in the order of 1kPa). It is possible that unsafe gasses may be emitted during extrusion cooking however comparisons with regular techniques are not known. It may be necessary to use a TCCS dedicated to the extruder.

Chemical/Physical Hazards (e.g., Heat (Dry/Wet), High Pressure, Electrical Shock, Metal Fragments, Volatiles, Weight (Falling Risk))

3.6 Shelf Life

Based on the technology, evaluate or describe the stability of the processed crop. Please state the stability of the harvested crops when stored under optimum conditions.

Depends on application (e.g., chemical composition, temperature, moisture)

3.7 Gravity Dependence

Does the processing technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? In other words, what would prevent the current processing equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity will affect crop functionality or shelf life
Extruder	Unknown (feeding may be affected gravity)	No

3.8 Processing Equipment Specifications

For each component in the post-harvest processing technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Emissions generated during processing	Crewtime (CM-h per use)
Theoretical (TRL 2)	25	0.3	10kW	None/very low	Volatiles	0.1h/kg
Ground-based (TRL 4)	50	1	100kW	None/very low	Volatiles	0.1h/kg

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to reach TRL=5	Labor costs to bring technology to TRL=5
Extruder	10,000	$1.0MM

3.9 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Technology	Describe equipment clean-up	CM-h per clean-up	Water usage (liters per cleaning)	Chemicals used for processing
Extruder	Flush with water soak the system with screw turning min. 10-15rpm. Fill and purge	0.5h	4-5L	Approved cleaning solutions

3.10 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
Extruder	>10 years	Spare screw and barrel Die head (?)	Calibrate and maintain once per year

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Misuse/operator error

3.11 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this processing technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
Extruder	Multifunctional	Volatiles Heat Water (Steam)	Volatiles in air Thermal Water

3.12 Post-harvest Processing Operations

Technology	Suitable for ground operations?	Suitable for planetary surface (partial gravity)	Unique to one processing technology? If not, list other technologies with same traits
Extruder	Yes	Yes	No (e.g., mixer, cooker, pump)

3.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
Extruder	Medium/high	Crop variation and ingredient composition Start-up Achieving steady-state

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature, Pressure, Moisture Flow rate, Motor torque	Yes	Yes	Yes

3.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
Extruder	Yes	Sensors Materials for fabrication	Miniaturization Modeling	Titanium construction Steam and volatiles collection/control

3.15 Data Sources

What references and data sources were used in completing this form?

4.0 Post-harvest Processing: General Purpose Mill (Cereals, Legumes, etc.)

4.1 If commercial, state manufacturer and specification or reference number: Brabender, Stephan Co., Buhler (Germany)

4.2 Current TRL (Refer to Appendix A): TRL 3

4.3 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

4.4 Functions - no information provided

4.5 Hazard Identification

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Biological, chemical, physical, e.g.,

Foodborne illness organisms

Mycotoxins

Metal fragments

Dust (explosion)

4.6 Shelf Life

Based on the technology, evaluate or describe the stability of the processed crop. Please state the stability of the harvested crops when stored under optimum conditions. Those conditions should be stated in the table (4th column).

Technology	Harvested crop shelf life (years)	Describe steps taken to ensure no loss in crop functionality (temperature, relative humidity, etc.)	Describe steps taken to ensure that ingredients remain stable after post-harvest processing.	Nutritional content of processed crop vs. original food state	Type of packaging needed to provide highest degree of food acceptability
GPM	>10 years (whole cereals) <1 year (cereal flours) 0.5 -3 years (whole legume seeds, and roots) <0.25-0.5 years (legume, and root flours)	< 0 C (the lower the better) Low RH Low temperature grinding system for soy to retain functionality of proteins	< 0 C (the lower the better) Low RH	Trace metal, some vitamin, and crude fiber loss in cereals, depending on level of bran removed	Packaging*: Opaque High barrier (moisture and oxygen) Low temperature (*assumes flour made ahead of time and held)

4.7 Gravity Dependence

Does the processing technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? In other words, what would prevent the current processing equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity will affect crop functionality or shelf life
GPM	Unknown	None anticipated

4.8 Processing Equipment Specifications

For each component in the post-harvest processing technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipmen t volume (m^3)	Power per use (kW)	Water usage (liters)	Emissions generated during processing	Crewtime (CM-h per use)
Theoretical (TRL 2)						
Ground-based (TRL 4)	Medium: 10-15kg	$0.2m^3$	1kW	Zero	Dust Possible volatiles	Depends on through put (<1h)

Can the equipment be automated? To what degree?

Yes

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to reach TRL=5	Labor costs to bring technology to TRL=5
Cereal grinder	2,000	$0.5MM

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

Dust minimization, containment, or removal

Cool grinding head for soy flour

4.9 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Technology	Describe equipment clean-up	CM-h per clean-up	Water usage (liters per cleaning)	Chemicals used for processing
GPM	Dry (e.g., vacuum, brush)	<0.5h	None	None

4.10 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
GPM	>10 years	Screens Grinder head Motor	Depends on use

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Hard objects

4.11 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this processing technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
GPM	Edible and inedible biomass reduction	Dust particles in air Generated heat Noise	Air system

4.12 Post-harvest Processing Operations

Technology	Suitable for ground operations?	Suitable for planetary surface (partial gravity)	Unique to one processing technology? If not, list other technologies with same traits
GPM	Yes	Yes	Yes

4.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
GPM	High	Low

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature Timer Motor speed Water activity meter	Yes	Yes	Yes

4.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
GPM	Yes	Air handling Temperature control Feed control	None	Weight/size reduction Noise abatement Temperature control Dust control

4.15 Data Sources

What references and data sources were used in completing this form?

5.0 Post-harvest Processing: Fruit and Vegetable Processor

5.1 If commercial, state manufacturer and specification or reference number: Armfield (U.K.), N.C. State (?), Dixie Canning Co. (Atlanta, GA), Stephan Co. (Columbus, OH)

5.2 Current TRL (Refer to Appendix A): TRL 1

5.3 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

5.4 Functions

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

General capabilities: Production of diced and sliced (size-reduced) fruits and vegetables, production of juices, other liquids (e.g., soups and starch suspension) and concentrates (e.g., sauces)

5.5 Hazard Identification

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Microbial, physical, e.g., heat, metal fragments, pressure,

5.6 Shelf Life

Based on the technology, evaluate or describe the stability of the processed crop. Please state the stability of the harvested crops when stored under optimum conditions. Those conditions should be stated in the table (4th column).

Technology	Harvested crop shelf life (years)	Describe steps taken to ensure no loss in crop functionality (temperature, relative humidity, etc.)	Describe steps taken to ensure that ingredients remain stable after post-harvest processing.	Nutritional content of processed crop vs. original food state	Type of packaging needed to provide highest degree of food acceptability
FVP	Raw fruits and vegetables (See USDA handbook 66)		Thermal processing Packaging	Some loss vitamin C Lycopene functionality increased	High moisture/oxygen barrier Protect from light

5.7 Gravity Dependence

Does the processing technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? In other words, what would prevent the current processing equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity will affect crop functionality or shelf life
FVP	Heating transfer effects	None

5.8 Processing Equipment Specifications

For each component in the post-harvest processing technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Emissions generated during processing	Crewtime (CM-h per use)
Theoretical (TRL 2)	Dicer Crusher Screen Heater Concentrator (e.g., vacuum, membrane)				Steam (vacuum) Water(membrane)	
Ground-based (TRL 4)						

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Concentrates need to be viscous and/or spreadable

Can the equipment be automated? To what degree?

Yes

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to reach TRL=5	Labor costs to bring technology to TRL=5
FVP	25,000	$5.0MM

5.9 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Technology	Describe equipment clean-up	CM-h per clean-up	Water usage (liters per cleaning)	Chemicals used for processing
FVP	Wet clean-up (CIP)	1h	20L	Approved cleaners and sanitizers

5.10 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
FVP	10 years	Screens Membranes	Based on usage (e.g., membrane change-out frequency)

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Membrane and screen damage

Membrane fouling and sanitation

5.11 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this processing technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
FVP	Multi-use Heat exchange	Solid waste (e.g., edible wastes such as skins and seeds)	Solid waste Water and steam Volatiles and odor

5.12 Post-harvest Processing Operations

Technology	Suitable for ground operations?	Suitable for planetary surface (partial gravity)	Unique to one processing technology? If not, list other technologies with same traits
FVP	Yes	Yes	No

5.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
FVP	High	Low

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature Pressure/vacuum Flow rates Refractive index	Yes	Yes	Yes

5.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
FVP	Yes	STOW	Miniaturization Process optimization	

5.15 Data Sources – no information provided

6.0 Post-harvest Processing: Low temperature Controlled Atmosphere System (LTCAS)

6.1 If commercial, state manufacturer and specification or reference number: Forma, Labco/Napco (?), Fisher, VWR, Maytag, GE, Samsung, LG, etc.

6.2 Current TRL (Refer to Appendix A): TRL 4

6.1 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

6.4 Functions

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

A Low Temperature Controlled Atmosphere System (LTCAS), including refrigerated and frozen storage, is a technology that may be used to provide acceptable and nutritious fresh and processed products.

LTCAS can extend the shelf life of salad crops and food products and at the same time it can preserve the freshness, acceptability and nutritional value of foods. The application of such a technology will result in the extension of the shelf life. This will be useful as it is unlikely that all harvested produce will be consumed immediately. Thus, the spoilage and waste will be reduced. In addition, in this way there will be fresh-like product available for consumption even when there is not any product ripened for harvesting.

Washing and use of sanitizers (such as chlorine, hydrogen peroxide and ozone) can be used prior to the packaging to ensure the safety of the product and the help the control of microbial growth. Reduced storage temperatures are generally required in order for the technology to be successful.

6.5 Hazard Identification

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Biological (e.g., psychotropic pathogens and spoilage organisms).

Loss of refrigeration.

Venting of refrigerator coolant gases to atmosphere.

6.6 Shelf Life

Based on the technology, evaluate or describe the stability of the processed crop. Please state the stability of the harvested crops when stored under optimum conditions. Those conditions should be stated in the table (4th column).

Technology	Harvested crop shelf life (years)	Describe steps taken to ensure no loss in crop functionality (temperature, relative humidity, etc.)	Describe steps taken to ensure that ingredients remain stable after post-harvest processing.	Nutritional content of processed crop vs. original food state	Type of packaging needed to provide highest degree of food acceptability
LTCAS	Depending on the crop, shelf life can be days, weeks, months, or years (e.g., cereals)	Control of the storage temperature, relative humidity and gas composition (e.g., oxygen, carbon dioxide, ethylene) is necessary	Same as before	Similar to the fresh food	Depending on the crop or product different storage conditions are required

6.7 Gravity Dependence

Does the processing technology have inherent mechanical or temperature limitations in fractional gravity or weightlessness? In other words, what would prevent the current processing equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity will affect crop functionality or shelf life
LTCAS	Partial gravity conditions should be sufficient for the successful application of the technology	No effect on the shelf life of the crop is expected

6.8 Processing Equipment Specifications

For each component in the post-harvest processing technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipment mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Emissions generated during processing	Crewtime (CM-h per use)
Technology: LTCAS Theoretical (TRL 2)						
Ground-based (TRL 4) Compartmentalized refrigerator/ freezer with atmosphere control	50kg	3	1-5kW	0	Food-associated volatiles Release of CA gases	0

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

No

Can the equipment be automated? To what degree? Both raw material preparation and packaging itself can be semi-automated.

Yes

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to reach TRL=5	Labor costs to bring technology to TRL=5
LTCAS	5,000	$3.0MM

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

There are no technical issues that are hindering the advancement of LTCAS from the current TRL 4 to TRL 5.

6.9 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crew time (CM-h per use), water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the wastewater stream.

Technology	Describe equipment clean-up	CM-h per clean-up	Water usage (liters per cleaning)	Chemicals used for processing
LTCAS	Spray-rinsing, use of approved cleaners and santizers, rinsing, dry wiping	0.2h	1-10L	Approved cleaners and sanitizers

6.10 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
LTCAS	10 years	Microprocessor Seals Sensors	Twice per year

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Ozone generation by electrical items degrades rubber and other polymers

6.11 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this processing technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
LTCAS	Decreased waste through use of less packaging	Released ethylene may ripen or degrade other products inadvertently	Air Water

6.12 Post-harvest Processing Operations

Technology	Suitable for ground operations?	Suitable for planetary surface (partial gravity)	Unique to one processing technology? If not, list other technologies with same traits
LTCAS	Yes	Yes	Yes

6.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
LTCAS	It is estimated that the technology is very reliable	If the defined procedures are followed precisely, the risk of not producing a stable product is small

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature Humidity Gas sensors (oxygen, carbon dioxide, ethylene, etc.) Microbial sensors	Yes	Yes	Yes

6.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
LTCAS	Yes	Refrigeration Gas composition control Microbial detection Gas scrubbing	Commercial interests (e.g., Maytag, GE)	Combination of controls and determination of appropriate compartmentalization conditions

6.15 Data Sources

What references and data sources were used in completing this form?

7. Post-harvest Processing: Ozone sanitation of salad crops

7.1 If commercial, state manufacturer and specification or reference number:

7.2 Current TRL (Refer to Appendix A): 4

7.3 Mission(s) for which this form is being completed (check one or more of the following options):

☒ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

7.4 Functions: Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Ozone can be generated by small, relatively lightweight ozone generators. The ozone produced is bubbled through water to produce ozonated water, which can be used to sanitize salad crops. From a more practical standpoint, fresh produce can be immersed in a container of water that has an inlet tube connected to an ozone generator. The container is then tightly sealed and ozone can be bubbled through the water for a few minutes to sanitize the produce.

Ozone has a far broader antimicrobial spectrum than chlorine and is capable of destroying spoilage and pathogenic microorganisms on fresh produce without leaving any chemical residues. A unique characteristic of ozone is that it decomposes to form pure oxygen.

Since water is a precious commodity in space environments, ozonated water used for washing salad crops treatment of wash water with a combination of ozonation and filtration. The treated wash water can then be used again for sanitizing more fresh produce and thus reduce water usage.

An electrical current is required to power the ozone generator.

7.5 Hazard Identification: Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

As with other oxidizing gases, ozone can be harmful to humans if exposure occurs for a long enough time at high concentrations of the gas. The Occupational Safety and Health Administration has set threshold limits for exposure to ozone. A level of 0.1 ppm for a normal 8-hr day/ 40-hr work week is the current Threshold Limit Value - Long Term Exposure Limit (TLV-LTE) for exposure to ozone in the work environment. A level of 0.3 ppm for 15 min is the current Threshold Limit Value - Short Term Exposure Limit (TLV-STE).

Ozone has to be generated onsite because the gas is immediately degraded in the treatment process. In addition, ozone degradation is hastened by its inherent instability. This almost immediate degradation of ozone after it is produced precludes storage of the gas. Therefore, it is not likely to get a sudden, uncontrolled release of large quantities of ozone.

Safety features can be built into ozone sanitation technology to the hazard (ozone). Reliable equipment is being manufactured for safe application of ozone technology.

7.6 Food Shelf Life – no information provided

7.7 Product Attributes – no information provided

7.8 Gravity Dependence – no information provided

7.9 Processing Equipment Specifications - no information provided

7.10 Equipment Clean-up - no information provided

7.11 Equipment Lifetime - no information provided

7.12 System Integration - no information provided

7.13 Reliability, Monitoring and Control - no information provided

7.14 Technology Advances - no information provided

8.0 Post-harvest Processing: Soymilk, Tofu, Okara, Whey System (STOW)

8.1 If commercial, state manufacturer and specification or reference number: CSC Study (Commercial Equipment), NASA

8.2 Current TRL (Refer to Appendix A): TRL 4

8.3 Mission(s) for which this form is being completed (check one or more of the following options):

☐ Mars Dual Lander Transit Vehicle

☒ Mars Dual Lander Surface Habitat

☒ Evolved Mars Base

Please only check more than one of the above options if all information for all criteria in this form would be completely identical for the checked missions. If ANY of the criteria are mission-specific, then please submit a separate form for each applicable mission.

8.4 Functions

Please briefly describe the technology in terms of its general capabilities, functions, and versatility. Does the technology or material have any unique capabilities? Do unique requirements exist in order for the technology to be successful in its application?

Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops.

Some food preservation technologies may be used to preserve the processed ingredients.

Convert immature (fresh) green or mature wet or dry soybeans into soymilk, for direct consumption, or further processing into yogurt, tofu, etc.

8.5 Hazard Identification

Identify and quantify (when possible) all hazards present during nominal operation of the technology. Please list these hazards regardless of ancillary safety features. Examples of ancillary safety features include but are not limited to containment systems, microbial filters, and pressure relief valves. Can adequate safety features be incorporated into the system design to control these hazards? Is it expected that the current hazards will be lessened or eliminated by further technology development? (Please explain.)

Hazard: odor into environment; Microbial hazard - must be consumed , further processed, refrigerated or frozen (for texturized tofu products). Physical injury if blades are not handled properly. Hazards could be lessened with further study (currently ongoing).

Electrical

HEA

8.6 Food Shelf Life

Based on the technology, state the shelf life (in years) of the end food product. Include the necessary storage conditions (temperature, relative humidity and pressure) and packaging to obtain the maximum shelf life.

	Shelf life	Storage temperature	Storage relative humidity	Storage pressure	Packaging type
Fresh soymilk Fresh tofu Frozen tofu	~5 days if refrigerated ~5 days if refrigerated ~years	40 F 40 F -20 F	NA	NA	Sealed container

At ambient temperature, does the shelf life change? If so, what is the new shelf life?

Yes. 4 hours (Room Temperature)

If a different packaging material is used (e.g., a more permeable material), what is the resulting shelf life at ambient temperatures? Would this packaging material be appropriate for the food preservation process?

No change.

8.7 Product Attributes

Based on the technology, state the product attributes of the end food product. Compare the attributes to the fresh product, either raw ingredient or if the food item had been prepared for immediate consumption in the home (not processed for longer shelf life). Use a scale of 1 – 9 where 1 is very poor and 9 is excellent.

Dependent upon soybean cultivar and process used.

	Nutrition	Flavor	Color	Odor	Texture
Raw (dry) Food	2	2	8	2	2
Processed Food (milk) Tofu Frozen tofu	7 9 9	5 8 9	8 8 7	5 8 8	8 8 (depends upon type made 9 (meat-like)

8.8 Gravity Dependence

Does the technology have inherent limitations in fractional gravity or weightlessness? In other words, what would prevent the current equipment from being operated upside down in a terrestrial environment?

Technology	Describe technology gravity dependence	Describe whether fractional gravity or changes in atmospheric conditions will affect crop functionality or shelf life
STOW	None (sealed system during process)	

8.9 Processing Equipment Specifications

For each component in the food preservation technology (including each pre- and post-processing step), estimate the theoretical (if technology is not ground test-ready) and ground–based test-ready equipment attributes. Values should be based upon operation and maintenance during nominal operation.

	Equipmen t mass (kg)	Equipment volume (m^3)	Power per use (kW)	Water usage (liters)	Crewtime (CM-h per use)
Theoretical (TRL 2)					
Ground-based (TRL 4)	10kg	0.7m^3 (inc. computer)	1kW	40L	0.75h

Can the equipment be automated? To what degree?

Yes. In progress NASA – STOW. Approx. 90% automated.

Is there an optimal food texture for this technology to be effective? If so, what is this texture?

Depends on end product and people's preference, soft/hard, thick, thin, chewy, etc.

Are the mass, volume, power, and crewtime numbers based on a currently existing system. If not, are these numbers scaled based on the existing equipment? If scaled, what scaling factors were used?

YES

If the TRL is currently less than 5, estimate the amount of labor hours, labor costs and other costs required to bring the technology to a TRL of 5 (test validation)?

Technology	Labor hours to bring technology to TRL=5	Labor costs to bring technology to TRL=5
STOW	2,000h	$0.2MM

What unresolved technical issues are hindering the advancement of this technology from the current TRL to TRL 5 (or to the next TRL if the current TRL is 5 or greater)? Which of these research issues are "cross-cutting", meaning that they will benefit other technologies as well as this one, if resolved? If it is claimed that a research issue is "cross-cutting", specify which other technologies would benefit from resolution of the issue.

Automation; soybean cultivar; refrigeration and freezing impact this area; waste utilization; miniaturization of valves

8.10 Equipment Clean-up

Provide information on the process for cleaning and sanitizing the equipment. Include crewtime, water usage and chemicals that are needed. Please keep in mind that the chemicals used should be easily removed from the waste water stream.

Material/ Technology	Describe equipment clean-up	Water usage (liters per cleaning)	Chemicals used for processing	CM-h per clean-up
STOW	Clean water, and sanitize	20L	Sanitizer - peroxide	0.5h depending upon equipment

8.11 Equipment Lifetime

Describe the expected lifetime of the food processing equipment. List the replacement or expendable parts, their costs, and expected schedule for replacing these parts. What is the maintenance schedule for the equipment?

Material/ Technology	Average equipment lifetime	Replacement or expendable parts and their costs	Recommended maintenance schedule
STOW	>2 years	Grinder parts Pump Screen	Regularly, after each run

What relevant compounds and circumstances will degrade the performance of or damage the technology?

Hard beans; power failure; motor failure; pump failure (if used)

8.12 System Integration

Are there any potential indirect benefits/detriments to the rest of the life support system or vehicle from this technology? The life support systems would include air, water, solid waste management, biomass, and thermal.

Technology	Potential indirect benefits	Potential indirect detriments	Affects which life support system
STOW or equivalent	Can be used for multiple foods Waste streams (whey and okara) can be used in other products	Odor	Air, liquid and solid waste

8.13 Reliability, Monitoring and Control

What is the reliability of this technology? What is the risk that the technology does not produce a stable food product?

Technology	Describe technology reliability	Evaluate technology risk
STOW or equivalent	Unknown	Low

What sensor data and controls are necessary to keep this process functioning properly? What data processing is needed to relate the sensor data to the control data?

Type of sensor data needed	Sensor available?	Controls needed for process	Data processing needs
Temperature Timer	Yes	Time/temp. Flow Mixer	Recorder

8.14 Technology Advances

Technology	Do technologies exist that are similar to the technology being discussed in this worksheet?	What other types of technologies would help the technology being discussed in this worksheet?	What steps are being taken to improve the technology being discussed in this worksheet?	Please recommend improvements to the technology being discussed in this worksheet?
STOW	Yes	Analytical	NASAFTCSC and NASA STOW Miniaturization Optimizing process parameters	

8.15 Data Sources – no information provided